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ERP Markers of Auditory Go/NoGo Processing

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ERP Markers of Auditory Go/NoGo Processing

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Certification

I, Jack Fogarty, declare that this thesis, submitted in fulfilment of the requirements for the award of the degree Doctor of Philosophy, from the University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualifications at any other academic institution.

Jack S. Fogarty

June 11, 2020

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Formatting Statement

This doctoral thesis has been prepared and presented in a journal article compilation style format. Each chapter is based on a published or submitted journal article written by the author of this thesis, as indicated in the foreword of each chapter, with the exception of the general introduction and final discussion chapters. A compilation style format was deemed appropriate to achieve the benefits of peer review throughout the development of this thesis and the ongoing research programme.

List of Thesis Journal Article Publications

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2019). Sequential processing in the classic oddball task: ERP components, probability, and behavior. *Psychophysiology, 56*(3), Article e13300. https://doi.org/10.1111/psyp.13300

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Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2020). The first 250 ms of auditory processing: No evidence of early processing negativity in the Go/NoGo task. *Scientific Reports, 10*(1), Article 4041. https://doi.org/10.1038/s41598-020-61060-9

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (submitted). NoGo P3a cannot index response inhibition: A single-trial latency-adjusted ERP analysis.

Abstract

The Sequential Processing Schema is a data-driven model that uses event-related potential (ERP) components to chart the important psychophysiological processes activated when completing auditory equiprobable Go/NoGo tasks. This model is useful for measuring experimental effects on basic cognitive processes and provides a valuable framework to synthesise and test ERP component theories. Determining the cognitive and behavioural correlates of ERP components is critical for understanding their functional significance and utility in psychology. Additional research is also needed to refine the conceptualisation of the ERP components and cognitive processing requirements in equiprobable Go/NoGo tasks, which are commonly used in psychophysiological research. To do that, robust data-driven methods such as temporal Principal Components Analysis (PCA) are needed for effective ERP component quantification and analyses of the Go/NoGo ERP component 'processing' series. This doctoral thesis aimed to clarify ERP component functionality and refine our understanding of equiprobable Go/NoGo tasks by developing the Sequential Processing Schema and exploring how ERP/PCA components relate to cognitive and behavioural processing under different Go/NoGo task conditions. Study 1 compared the ERP component processing series associated with auditory equiprobable and oddball variants of the Go/NoGo task. The manipulation of probability and the relevant modulation of the ERP component series reflected a shift in particular cognitive demands or task requirements, which promoted the conceptual development of component functionality and the generalisability of the Schema. The results of Study 1 questioned the identity of a core ERP component (i.e., Processing Negativity) previously linked to auditory Go/NoGo processing; this was pursued in detail in Study 2, which aimed to clarify the ERP components associated with early information processing in auditory equiprobable and 'frequent Go' variants of the Go/NoGo task. Stimulus probability differences (this time the inverse of Study 1) were again used to elucidate component functionality and provide insight into the cognitive task demands. Study 3 and 4 explored ERP component functionality by examining Go stimulus- and response-locked ERP averaging effects, and the link between the equiprobable NoGo P3a and motor response inhibition. Studies 1–4 provided insight into the sequential processing requirements in auditory equiprobable Go/NoGo tasks, and the associated ERP/PCA components, promoting the development of common ERP components as indices of cognitive processes. These outcomes clarified the utility of the equiprobable Go/NoGo task, and highlight important similarities and differences between Go/NoGo and oddball processing, encouraging ERP theory development and integration between those common research paradigms. An update to the Schema was proposed to accommodate the ERP findings and reflect the refined interpretation of equiprobable Go/NoGo processing developed in this thesis, including a shift in the conceptualisation of the sensory processing and inhibitory requirements in the equiprobable task. This was considered to improve the conceptual framework of the Schema and its utility for charting the cognitive and behavioural processing in different task conditions. The outcomes also provide novel insight into how healthy young adults process information and encourage further studies of sequential processing to help delineate abnormalities in cognitive processing related to different psychopathologies.

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Chapter 1. General Introduction

Sequential processing perspectives are concerned with the temporal characteristics (e.g., latency, order, and duration) of distinct cognitive events. The purpose of this doctoral research was to develop a sequential processing schema proposed by Barry and De Blasio (2013), which aims to chart the major cognitive events in auditory equiprobable Go/NoGo tasks, using the task-related series of event-related potential (ERP) components identified with temporal principal components analysis (PCA). This schema represents a holistic data-driven conceptualisation of auditory equiprobable Go/NoGo processing that may facilitate research utilising this cognitive task. However, further research linking ERP components to cognitive and behavioural demands is needed to clarify the functional significance of PCA-derived Go/NoGo ERP components and the cognitive requirements in auditory Go/NoGo tasks.

1.1. Important ERP fundamentals

ERPs acquired from electroencephalographic (EEG) data are scalp-recorded electrical signals that are synchronised with an event, like the presentation of a stimulus or a behavioural response (Landa et al., 2014; Picton et al., 2000). ERP data are considered to reflect the sum of postsynaptic potentials volume-conducted to the scalp from clusters of cortical pyramidal neurons, which fire together while processing information (Sur & Sinha, 2009). Figure 1 presents an example of an auditory stimulus-locked ERP. The neuronal origin of ERPs, as well as their high temporal resolution (in ms), and the ability to decompose electrical signals into measurable components, makes ERPs valuable for studying sequential processing (Landa et al., 2014; Luck, 2005; Picton et al., 2000; Woodman, 2010).

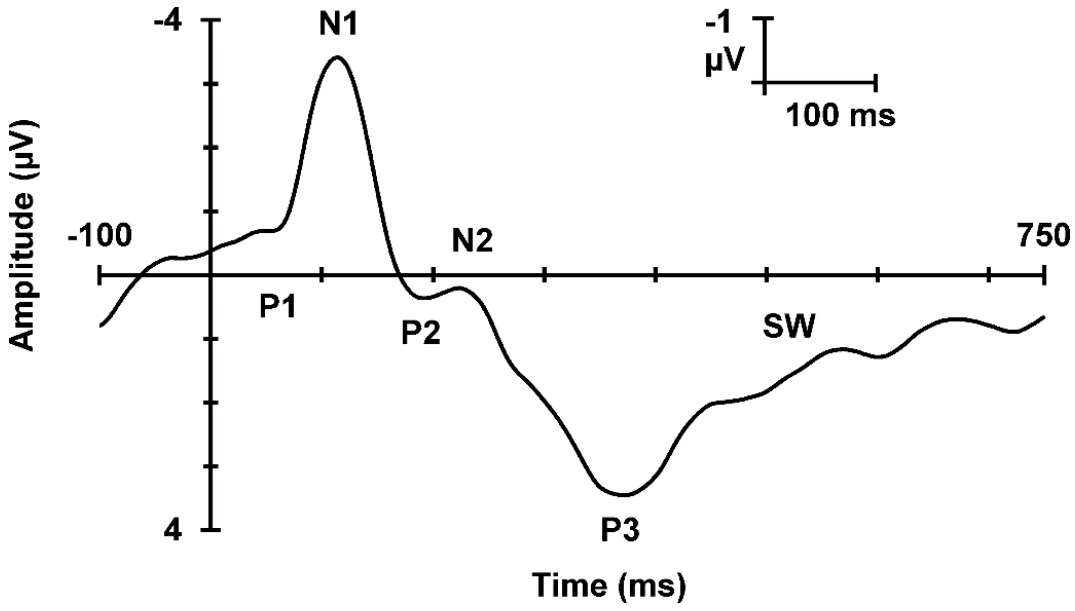

Figure 1. A typical auditory stimulus-locked ERP averaged over the midline (Fz, Cz, and Pz) across 40 subjects. Major ERP components are labelled around the ERP at their approximate peak latency. SW refers to the slow-wave component.

ERP *components* are constructs that represent functionally distinct intracranial activity of neuronal populations (or networks) that contribute to the total scalp-recorded ERP waveform (see Donchin et al., 1978; Fabiani et al., 1987). By convention, components are operationally defined and labelled according to observable features within the ERP data that reflect their controlled ERP variance; namely, their temporal and spatial (topographic) features (Donchin et al., 1978; Picton et al., 2000; Woodman, 2010).

A typical series of ERP components are labelled in Figure 1. The auditory N1 component, for example, is operationally defined as a negative-going peak in the ERP waveform, which peaks at frontocentral scalp sites ~100 ms poststimulus; the label N1 (or N100) reflects both its polarity (i.e., negative) and its order (i.e., it is the first negative peak) or approximate timing (i.e., 100 ms). Theoretically, N1 represents complex neuronal activity (which can be partitioned further into subcomponents) associated with auditory stimulus processing and attention (see Näätänen & Picton, 1987). Evidence from ERP and other neuroimaging studies frequently support this association (e.g., Crottaz-Herbette & Ragot, 2000; Ibrahim et al., 2018; Liem et al., 2012; Paiva et al., 2016) and the component has become a valuable tool used to index auditory processing in psychophysiological research (e.g., Koerner & Zhang, 2015; Salisbury et al., 2010). However, despite its established value there is still a lot to learn about the functional significance of N1 and the various overlapping components in this complex, and many other ERP components.

1.2. ERP methodology

ERP research typically explores three features of ERP components; the amplitude, latency, and current source density in 3D cortical subspace, reflecting the level of activation, timing, and the source location (and activity) of the underlying neuronal response. Numerous methods of ERP quantification are available to measure these features. Here, a brief overview is provided of the methods and considerations needed to understand the general approach taken to quantify ERPs in this doctoral research; interested readers are encouraged to consider the works by Luck (2005) and other authors (e.g., Cohen, 2014; Handy, 2005; Hoormann et al., 1998; Koenig et al., 2014; Picton et al., 2000) for more comprehensive reviews regarding various ERP techniques.

1.2.1. Quantifying ERP components

Traditionally, the latency and amplitude of ERP components are measured directly from ERP waveforms using peak or area measures (e.g., peak-picking and centre-of-area) that have been central to establishing ERP components as a discrete field of study. These methods are attractive because they are not computationally intense and they can be sensitive to important ERP variance; however, this also means that they are highly unstable in the presence of electrical noise (Chapman & McCrary, 1995; Donchin & Heffley, 1978). Traditional ERP measures are also limited by their subjective nature, as researchers need to select, somewhat arbitrarily, peaks or areas of the waveform to measure (Donchin, 1966; Van Boxtel, 1998). More importantly, they

cannot account for the influence of overlapping ERP components. Traditional measures will collapse the ERP variance from any components that overlap at any measured time-point (peak) or time-period (area), resulting in an unknown level of "misallocation of variance", the incorrect attribution of an experimental effect to a particular component (see Beauducel & Debener, 2003; Donchin & Heffley, 1978; Wood & McCarthy, 1984).

The shortcomings of the traditional ERP measures mentioned above have been a major impetus for the development of more advanced techniques to objectively decompose ERP data into distinguishable components. Numerous methods have been proposed for that purpose, including measures of global field power (e.g., Lehmann & Skrandies, 1980), iterative waveform decomposition (e.g., Ouyang et al., 2011), and various types of blind signal separation and factor analyses (e.g., Cong, 2019; Donchin, 1966; Makeig et al., 1996, 1997; Mørup et al., 2006; Rogers, 1991; Scharf & Nestler, 2018a). Here, the focus of this doctoral research is on the use of Principal Components Analysis (PCA), a linear decomposition akin to factor analysis that is widely used to quantify ERP components (e.g., Anderson et al., 2015; Chapman et al., 2011; Cong et al., 2014; Curran & Dien, 2003; Deveney & Deldin, 2004; Kayser et al., 2003; Macatee et al., 2018; Mecklinger et al., 1992; Siegel et al., 2003; Vanderploeg et al., 1987; Widmann et al., 2018; Winterer et al., 2003).

1.2.2. Temporal PCA

Temporal PCA extracts factors based on the temporal covariance in the ERP data (Dien & Frishkoff, 2005; Donchin, 1966; Van Boxtel, 1998); thus, temporal PCA components are considered to represent factors of ERP data (summarising linear combinations of variance) that vary in weight (or amplitude) over time, providing a more realistic virtual model of discrete electrophysiological processes than voltage fluctuations measured directly from the ERP waveform.

Notably, PCA provides an objective (data-driven) method to identify important and *latent* ERP components (see Dien & Frishkoff, 2005; Donchin, 1966; Kayser & Tenke, 2003; Van Boxtel, 1998). It also reduces the issue of component overlap and improves the statistical properties, stability, and interpretability of ERP measures through factor extraction and rotation (Beauducel & Debener, 2003; Beauducel et al., 2000; Browne, 2001; Chapman & McCrary, 1995; Dien, 1998; Kayser & Tenke, 1998, 2003, 2006a; Scharf & Nestler, 2018b, 2019; Van Boxtel, 1998).

PCA is equivalent to factor analysis in its application to ERP data (Dien et al., 2005). For that reason, many issues related to the factor analytic model concern PCA in this context, including the choice of association matrix (correlation vs. covariance), the number of factors to extract and the threshold measure to determine this, and the type of rotation used to achieve simple structure; that is, a more parsimonious and interpretable solution in the factor pattern matrix (see Browne, 2001; Thurston, 1947; Yates, 1988).

1.2.3. Considerations for PCA

A consensus has been reached indicating that the covariance matrix is the ideal PCA association matrix for ERP research, as it improves the interpretability of the factors by maintaining the scale of the input (i.e., microvolts; Donchin & Heffley, 1978; Van Boxtel, 1998). More importantly, it can provide more accurate factor solutions than those derived using a correlation matrix (see Dien, 2006; Dien et al., 2005; Kayser & Tenke, 2003, 2005, 2006a); although, notably, the accuracies of correlation- and covariance-based analyses are considered to converge as more factors are rotated (Dien et al., 2005; Kayser & Tenke, 2003).

The number of factors to extract and the threshold method to use is less clear. Several authors encourage the use of fixed eigenvalue or variance thresholds (e.g., Kaiser, 1960), scree tests (Cattell, 1966; Cattell & Jaspers, 1967) or parallel analyses (Horn, 1965; Hayton et al., 2004) to limit factor retention. These methods provide reasonable cut-offs that are considered to simplify the factor solution and reduce multiplicity in further analyses (see Chapman & McCrary, 1995; Dien, 2006; Dien et al., 2005). However, as noted by Kayser and Tenke (2003, 2006a), under-extraction can result in unstable or degraded factor solutions whereas rotating all factors can improve the stability of the factors. Statistical analyses can also be applied to a select number of factors *after* unrestricted rotation to avoid excessive analyses. An unrestricted approach can also facilitate the identification of small but physiologically meaningful factors. Moreover, while there are concerns for both under-extraction and over-extraction, over-extraction is thought to be much less of an issue (Fava & Velicer, 1992, 1996), and it is recommended that under-extraction be avoided even at the risk of over-extraction (Wood et al., 1996).

The factor analysis model is ‘under-determined’ in that an infinite number of factor loading matrices could account for any given association matrix (Mulaik, 2005). To resolve this indeterminacy, factors are rotated using mathematical transformations that redistribute variance across the extracted factors to identify a unique and parsimonious solution. This is often conducted in line with Thurston’s (1947) principles of simple structure, namely, that each variable in a factor matrix should contain at least one zero, reflecting a reduction in the complexity of the data (Kieffer, 1999; Yates, 1988). In this context, complexity is typically defined as the amount of *cross-loading* in the factor matrix; that is, where multiple factors load on the same set of variables (Browne, 2001). For temporal PCA, the variables are timepoints, thus *perfect* simple structure (i.e., no cross-loadings) would involve a factor solution in which only one extracted ERP factor loads onto any given timepoint.

Many rotation methods have been proposed to minimise complexity in factor solutions and there are several excellent reviews considering their distinct capabilities (e.g., Browne, 2001; Dien, 2010; Kieffer, 1999; Sass & Schmitt, 2010; Schmitt & Sass, 2011; Thompson, 2004). In general, there are two major classes of factor rotation, known as orthogonal and oblique rotation (Scharf & Nestler, 2018b). Orthogonal rotations aim to find a parsimonious solution while

ensuring that all factors remain uncorrelated, whereas oblique rotations relax this constraint and allow inter-factor correlations.

In the ERP literature, orthogonal rotations are used because they provide highly stable, replicable results, and it is desirable to extract uncorrelated factors, as this simplifies subsequent analyses (Kieffer, 1999; Schmitt & Sass, 2011; Van Boxtel, 1998). However, strict orthogonality constraints are often considered to be unrealistic, and minimising inter-factor correlations can inflate cross-loadings (Sass & Schmitt, 2010; Scharf & Nestler, 2018a; Schmitt & Sass, 2011). It is strongly argued that oblique rotations be used to attain more plausible solutions (Dien, 1998, 2006; Dien et al., 2005; Scharf & Nestler, 2018a, 2018b, 2019). Relaxing the orthogonality constraint minimises cross-loadings further and provides closer approximations to perfect simple structure. However, in turn, this can increase redundancy and inflate the inter-factor correlations throughout the factor solution, potentially reducing the discriminant validity of the extracted factors (Kayser & Tenke, 2006a; Schmitt & Sass, 2011; Marsh et al., 2009).

Simulation studies show that oblique factor rotations like Promax can outperform others in particular circumstances (e.g., Browne, 2001; Dien, 1998; Dien et al., 2005; Sass & Schmitt, 2010; Scharf & Nestler, 2018b, 2019). However, as indicated by Schmitt and Sass (2011), the 'correct' rotated solution cannot be known given the indeterminacy of the factor model. Researchers must consider the advantages and disadvantages of each rotation method and select those that provide the most appropriate solution for their data and purpose. In this doctoral research, Varimax was used to maximise the stability, interpretability, and simplicity (minimal redundancy) in unrestricted factor solutions, as well as to maintain comparability with previous PCA research in the selected research paradigm.

1.2.4. ERP component source localisation

Identifying the neuronal sources of an ERP component is important for its conceptual development and for interpreting study outcomes in relation to brain structure and functioning. However, this is difficult considering the ambiguous nature of the *inverse problem*; that is, any given scalp topography could be explained by a countless number of neuronal source configurations (Nunez & Srinivasan, 2006). Thus, to find a unique and meaningful solution, it is necessary to rely on a source model, involving several *a priori* assumptions about the generation of scalp potentials (Michel et al., 2004).

In general, there are two types of source models: dipolar or distributed source models. Dipolar models assume that a select and often small number of sources (i.e., 'current dipoles' representing specific neuronal assemblies) can account for the scalp-recorded data. This method is useful when the number (and possibly orientation and location) of sources is known; however, this is extremely difficult to conclude *a priori*, and this 'over-determined' approach can easily exclude important dipole activity (He & Ding, 2013; Michel et al., 2004).

Distributed models make no strict assumption about the number of sources and effectively model the brain volume as a 3D grid of numerous (often thousands) of current dipoles that are fixed in location and orientation (Grech et al., 2008). This is a more objective approach that is ideal for exploratory analyses where the number of sources is unknown; however, additional constraints are needed to find an optimal source solution using such an "under-determined" approach (Asadzadeh et al., 2020; Halder et al., 2019; He & Ding, 2013; Michel & Brunet, 2019; Michel et al., 2004; Wendel et al., 2009).

Numerous EEG source localisation algorithms are available to calculate distributed inverse solutions, and these have been reviewed in detail by Michel et al. (2004, 2019), and by others (e.g., Anderer & Saletu, 2013; Asadzadeh et al., 2020; Baillet et al., 2001; Grech et al., 2008; He & Ding, 2013; Wendel et al., 2009). The important differences between these algorithms are in the criteria they use to identify a unique and 'optimal' solution to the inverse problem (Michel et al., 2004).

The inverse algorithm used in this doctoral research is the exact low-resolution electromagnetic tomography (eLORETA) proposed by Pascual-Marqui et al. (2007, 2009). This is a Minimum Norm (MN) approach incorporating a Laplacian constraint, which effectively selects the weighted MN solution with the smoothest spatial distribution, assuming that the activity is similar at neighbouring dipoles. This assumption has some physiological plausibility, as the activity of adjacent neurons can be highly synchronised (e.g., Haalman & Vaadia, 1997; Llinás, 1988; Sukov & Barth, 1998); however, this correlation between adjacent neurons is not necessarily evident at the scalp level, so this physiological justification should be considered tentative (Fuchs et al., 1994, 1999; Michel et al., 2004).

eLORETA and its precursors (i.e., LORETA, sLORETA) have been shown to provide higher accuracies than many other inverse solutions, including standard and weighted MN (Pascual-Marqui, 1999; Pascual-Marqui et al., 2011; Soufflet & Boeijinga, 2005; Yao & Dewald, 2005), Backus-Gilbert and Weighted Resolution Optimisation (Pascual-Marqui, 1999), Dale (Pascual-Marqui, 2002), and common beamformer methods (Halder et al., 2019); this superiority is particularly evident at greater depths in the 3D solution space and in the presence of noise, contributing to its wide uptake by the field. The accuracy of LORETA has also been supported extensively using fMRI and EEG/ERP data (Pascual-Marqui et al., 2002). Moreover, eLORETA provides better solutions than LORETA and sLORETA (Jatoi et al., 2014), with zero localisation error in the presence of noise (Pascual-Marqui, 2007, 2009; Pascual-Marqui et al., 2011).

The selection of eLORETA for this research was based on its extensive validation and superior accuracy at depth, and in the face of noise, relative to other state-of-the-art methods. MN-type solutions are also the most commonly used throughout the EEG source localisation literature (Michel et al., 2004). However, this is not to say that eLORETA provides the best inverse solution. LORETA is known to have a lower spatial sensitivity than other methods due to

the Laplacian constraint (see He & Ding, 2013; Michel et al., 2004). This applies to eLORETA; hence, it is recommended for exploratory research, while other methods with higher spatial resolution (e.g., LCMV beamformer) are advised for targeted source analysis (Halder et al., 2019). Considering this, and the under-determined nature of the inverse problem, the source solutions identified in this doctoral research should be thought of as a guide for the conceptual development of the Go/NoGo ERP factors derived using temporal PCA, rather than a definitive map of their neuronal sources.

1.3. Go/NoGo, oddball, and equiprobable tasks

The overarching purpose of this doctoral thesis was to continue an ERP/PCA data-driven conceptualisation of simple auditory equiprobable Go/NoGo task processing. Go/NoGo tasks require individuals to discriminate and respond to two types of stimuli: Go (targets) and NoGo (nontargets). Thus, like other active two-choice tasks, the Go/NoGo task requires individuals to detect and discriminate between presented stimuli to select and activate the correct behavioural response. However, Go/NoGo tasks are unique in that no explicit response is made to NoGo stimuli, providing a valuable context to study both response activation and true motor inhibition (Gomez et al., 2007). Go stimuli can also be more relevant (or significant) to participants than NoGo stimuli, enabling research into attentional control and the processing of relevant (vs. irrelevant) information (Barry & Rushby, 2006).

Traditionally, Go stimulus probability is increased so that individuals anticipate and prime Go responses, resulting in greater inhibitory demands in the rarer NoGo trials, and facilitating research into motor control (e.g., Low & Miller, 1999; Wessel, 2018). Alternatively, in active 'oddball' variants of the task, Go probability is lowered relative to NoGo probability to increase the demand on relevant (target) stimulus processing, and facilitate research into attention (e.g., Näätänen, 1990; Rockstroh et al., 1996); however, as NoGo stimuli are frequent (standard), the inhibitory requirements in NoGo trials are considered to be diminished. Figure 2 shows the results of a PubMed literature analysis (described in Appendix B), which indicates that discrete research literatures have developed for the Go/NoGo and oddball tasks despite their similarity. Only seventeen research articles referred to both Go/NoGo and oddball tasks, and only one study was common to both the Go/NoGo and oddball probability literatures, suggesting that there is little crossover between the two fields; this separation generally follows the different Go and NoGo demands associated with each task.

Common to both the Go/NoGo and oddball literatures is the *equiprobable* Go/NoGo (or oddball) task, which features an equal number of Go and NoGo stimuli. This design is typically used to control stimulus probability effects (e.g., Banquet et al., 1981), but is also the most efficient method for recording both Go and NoGo data (Barry & De Blasio, 2013, 2015; Key & Yoder, 2013; Pfefferbaum et al., 1985), which is perhaps why equiprobable tasks are considered to be the most widely used Go/NoGo variant (according to a review of the published Go/NoGo

literature between 1993 and 2016: Wessel, 2018). However, that conclusion is for equiprobable variants relative to all other discrete probability levels; sorting the studies in Wessel's (2018) review according to those that use tasks that are equiprobable, biased towards Go (Go $p > .5$), or NoGo (NoGo $p > .5$), reveals that traditional 'frequent Go' variants of the task are somewhat more common. Regardless, equiprobable tasks are useful and popular for studying both Go and NoGo processes together in one study.

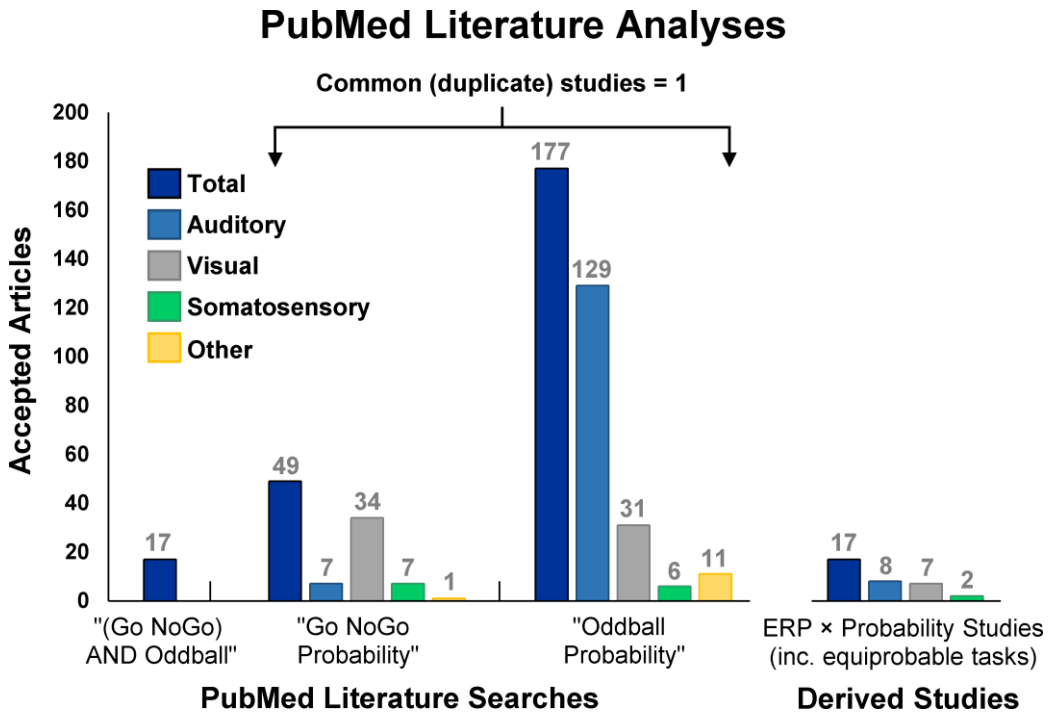

Figure 2. The results of the literature analyses based on separate PubMed searches for: *(Go NoGo) AND Oddball*, *Go NoGo Probability* and *Oddball Probability*. The total number of accepted articles are broken down and colour-coded according to the stimulus modality used (i.e., auditory, visual, etc.). Seventeen ERP studies involving statistical analyses of probability effects that included an equiprobable condition were derived from the reviewed articles. Further details on these literature analyses are available in Appendix B.

The extent to which equiprobable processing resembles the traditional Go/NoGo or oddball processing is debatable, especially in regard to the cognitive requirements that are sensitive to stimulus probability (e.g., selective attention and inhibitory demands). Indeed, theories developed using traditional Go/NoGo or oddball tasks are often directly generalised to equiprobable task measures in accordance with the broader Go/NoGo or target/nontarget context, despite the dearth of research formally comparing the processing and behaviour in these tasks. An example of this is the interpretation of the equiprobable NoGo P3 (P3a), an ERP component that can be considered to represent either motor response inhibition (e.g., Kamarajan et al., 2005) or attentional processing (e.g., Ravden & Polich, 1998) from traditional Go/NoGo or oddball task perspectives, respectively.

Useful comparisons of Go/NoGo and oddball task processing are available in studies investigating stimulus probability effects on ERPs within subjects. According to the literature analysis in Figure 2, seventeen studies have statistically compared equiprobable task ERP components with those in the traditional Go/NoGo or oddball tasks. However, the majority of these studies focus on a small number of ERP components using traditional ERP measures (Bruin & Wijers, 2002; Dalbokova et al., 1990; Dimigen et al., 2009; Eliades et al., 2014; Heinrich & Bach, 2008; Hepsomali et al., 2019; Hull & Harsh, 2001; Keskin-Ergen et al., 2014; Nakajima & Imamura, 2000; Nakata et al., 2005; Pfefferbaum & Ford, 1988; Rasmusson & Allen, 1994; Rüsseler et al., 2003). This focused insight is valuable; however, clarifying task (i.e., probability) differences on a larger range of ERP components is needed to contextualise these effects in the broader Go/NoGo processing series, to achieve a more complete understanding of the distinct cognitive requirements in each task variant.

In the auditory modality, several studies have analysed Go/NoGo task differences across a broader range of ERP components (Banquet et al., 1981; Brigham et al., 1995; Polich et al., 1994; Polich & Margala, 1997; Spencer & Polich, 1999). These studies consistently show an increase in P3 amplitude as stimulus probability decreases, although the probability effects on other components (i.e., N1, P2, N2) are less reliable, likely due to the use of traditional ERP measures, limited electrode sites (n = 1–5), and sample sizes (N = 6–16)[1].

Squires et al. (1975) used PCA to examine Go/NoGo stimulus probability effects and noted a better separation of effects across six factors (i.e., N1, P2, N2, P3a, P3b, and SW) after minimising the overlap evident in their traditional ERP measures. Duncan-Johnson and Donchin (1977) also studied auditory stimulus probability effects on a similar PCA factor series. These findings are detailed in Chapter 2, but it is notable that identifying similar factors across different probability levels suggests that common cognitive requirements are needed in each Go/NoGo (oddball) task variant. However, it may be that the temporal PCAs in these two studies were not sensitive enough to detect important task differences in the ERP processing series. Similar to the traditional probability research mentioned above, these early PCA studies involved small sample sizes (N = 6–10), limited scalp sites (3–9), and few timepoints in the PCA (64 variables), limiting the sensitivity of the PCA and subsequent ERP analyses. More importantly, the ERP data were combined into one PCA, which extracts a fixed hierarchy of factors across the input conditions, potentially masking important differences in the ERP processing series by forcibly extracting a fixed (or comparable) set of PCA factors across task conditions. Separate PCAs should be applied to the ERP data from each condition to extract factors that model data within each condition more precisely (see Barry, De Blasio, Fogarty & Karamacoska, 2016).

[1] Brigham et al. (1995) included a sample of 54 children, although the study did not examine probability effects on ERP amplitudes, which is the focus of this thesis.

Studies decomposing richer ERP data with more contemporary techniques are needed to compare the wider Go/NoGo (and oddball) ERP processing series more rigorously to clarify the related cognitive requirements, as well as the ERP components, and general research utility associated with each Go/NoGo variant. Additional research is also needed to determine the functionality of the ERP factors in *simple* (i.e., uncued two-stimulus) variants of the equiprobable Go/NoGo task. This is important given that this simple task could provide researchers with an efficient and widely relevant tool to assess a range of fundamental neurocognitive functions. Additional insight into equiprobable tasks could also help to bridge or demarcate the Go/NoGo and oddball ERP literatures.

1.4. The Sequential Processing Schema

The Sequential Processing Schema proposed by Barry and De Blasio (2013) is a simple (ERP) data-driven framework, which uses a series of Go/NoGo ERP/PCA factors to chart the important cognitive stages (or events) associated with uncued auditory equiprobable Go/NoGo processing. The Schema's conceptualisation follows relevant ERP theories and research; hence, it is not a theory in and of itself, but is instead a workable model of Go/NoGo processing that can be used to synthesize and test a range of psychophysiological theories (or hypotheses) tied to common ERP components.

Using ERP/PCA factors to index cognitive processes is obviously not novel or unique. However, extracting and examining a comprehensive range of ERP factors can help delineate and contextualise experimental effects relative to the broader task processing requirements; this can increase the interpretability and relevance of ERP research, as opposed to focusing on one (or few) isolated ERP factor(s). Developing a *holistic*, *integrated*, *data-driven*, and *physiologically relevant* framework of Go/NoGo processing is also considered to be a valuable approach to refine our understanding of these tasks (and the related ERP components) and improve their application and interpretation within the wider research community. The PCA research underpinning the Schema reflects an effort to characterise the auditory equiprobable Go/NoGo processing series and to framework experimental effects in this manner, although further research is needed to clarify the functional significance of the related ERP/PCA factors and equiprobable task requirements.

The specific PCA method driving the Schema's development is outlined by Barry, De Blasio, Fogarty, and Karamacoska (2016). In brief, unrestricted covariance-based extraction of ERP factors is applied *without* the typical mean-correction applied to factor scores, to identify a complete and robust factor solution that can be interpreted directly in relation to the input ERP data (Dien, 2014; Dien & Frishkoff, 2005; Kayser & Tenke, 2003). Factors are then Varimax rotated to simplify the unrestricted factor solution. The outcome of this method is a highly replicable data-driven series of orthogonal ERP/PCA factors that represent discrete electrocortical processes related to a particular event.

Applying the aforementioned temporal PCA method to auditory equiprobable Go/NoGo ERP data generates the factor series associated with the proposed Schema, which has been extracted reliably over numerous studies that have examined variations in discrete Go/NoGo processes associated with changes in variables including ageing or cognitive development (e.g., Barry, De Blasio, & Cave, 2016), behavioural performance (e.g., Barry & De Blasio, 2015), and caffeine consumption (e.g., Barry et al., 2014).

Prior to this doctoral research, the Go/NoGo Schema was updated for young adults by Fogarty et al. (2018). As shown in Figure 3, auditory equiprobable Go/NoGo processing is marked first by four PCA factors representing P1 and three N1 components: N1-3, N1-1, and Processing Negativity (PN). In line with the broader ERP literature (e.g., García-Larrea et al., 1992; Hillyard et al., 1973; Lijffijt et al., 2009; Näätänen & Picton, 1987), and the prior version of the Schema (Barry & De Blasio, 2013), these factors were considered to reflect sensory and perceptual requirements common to each condition. The N1-1 factor was also considered to mark the beginning of stimulus categorisation following earlier PCA findings showing N1-1 amplitude differences between conditions in this task (Barry & De Blasio, 2013; Borchard et al., 2015). PN was thought to reflect a later stage of categorisation following Attentional Trace Theory (developed in the oddball literature) linking the component to selective attention (Näätänen, 1982, 1990). Successful stimulus categorisation is evident after PN with the onset of stimulus-specific ERP component processing sequences. For Go, further target processing and response activation is marked by factors representing P2, N2c, P3b, and a slow wave (SW); whereas for NoGo, nontarget processing is marked by N2b, P3a, and a late positivity (LP), which were considered to reflect the active control and termination of response processing in this task, similar to NoGo processing in traditional Go/NoGo tasks.

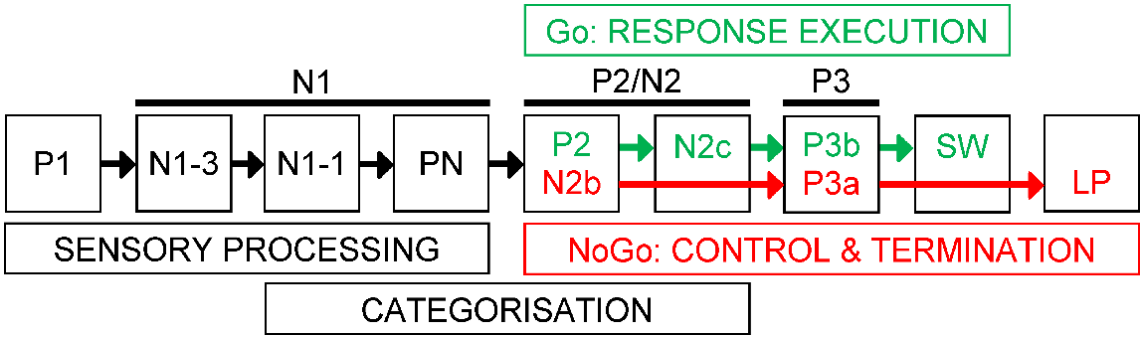

Figure 3. The Sequential Processing Schema updated for young adults in Fogarty et al. (2018).

The ERP component series in the Schema has supported the conceptualisation of equiprobable task demands and the interpretation of ERP component effects relative to other component-oriented functions in the Go/NoGo processing series (Griskova-Bulanova et al., 2016; He et al., 2018; Le et al., 2020; Melynyte et al., 2017; Nanda et al., 2019; Piispala et al., 2016, 2017). The related PCA research has also aided the conceptualisation, identification, and measurement of ERP components by providing a data-driven representation of their characteristic

features and potential subcomponents, separate from other overlapping ERP activity (Cespón & Carreiras, 2020; De Zorzi et al., 2020; Horat et al., 2016; Kamp, 2020; Kim et al., 2018; Kotchoubey & Pavlov, 2019; Mudar et al., 2019; Nguyen et al., 2017; Ponomarev et al., 2019; Proverbio et al., 2016; Wei et al., 2019). ERP findings linked to the Schema (such as the positive correlation between N2b amplitudes and commission errors: Barry & De Blasio, 2015; Fogarty et al., 2018) have also been adopted for the theoretical development of common ERP components (Baghdadi et al., 2017; Cheng et al., 2019; Howell et al., 2018; Hoyniak & Peterson, 2019; Quinzi et al., 2018; Verleger, 2020) or to support psychophysiological phenomena, such as the cognitive changes associated with aging or caffeine (Bailey et al., 2016; Kardos et al., 2020; Lin & Cheng, 2020; Maldanado et al., 2020; Yang et al., 2016). This illustrates the broader value of the schema-related research to the ERP literature; however, as mentioned, basic research into the functional significance of Go/NoGo ERP components is needed, especially given that traditional ERP findings may not apply to PCA factors.

1.4.1. Additional considerations

The Schema in Figure 3 reflects an interpretation of the PCA factor series extracted from simple auditory equiprobable Go/NoGo tasks, which builds on previous ERP research in this task (e.g., Falkenstein et al., 1995, 1999, 2002; Griskova-Bulanova et al., 2016; Melynyte et al., 2017; Sams et al., 1983) and the broader ERP literature. PCA studies using more complex equiprobable designs explore similar components, although the task requirements can differ substantially from that in simple Go/NoGo tasks (e.g., Barratt, 1987; Kałamała et al., 2018; Key et al., 2016). Similar PCA factors are also evident in classic *auditory* oddball tasks (see Brown et al., 2015; Bruder et al., 2002; Kayser & Tenke, 2006b, 2006c; Kayser et al., 1998, 2010; Tenke et al., 2008) and somewhat so in *visual* Go/NoGo or oddball tasks with only two stimuli (Dien et al., 2004; Fink et al., 2016; Kamp, 2020; Lavric et al., 2004; Lubman et al., 2007; Macatee et al., 2018; Matsuda & Nittono, 2015; Portella et al., 2014; Spencer et al., 1999).

N1, P2, N2, P3, and SW factors are also studied using PCA in *novelty* oddball tasks (e.g., Anderson et al., 2015; Behforuzi et al., 2019; Delplanque et al., 2005; Friedman, 1984; Goldstein et al., 2002; Kayser et al., 2014) and *cued* Go/NoGo or *stop-signal* tasks (e.g., Bruder et al., 1999; Camfield et al., 2018; Roberts et al., 1994; Verleger et al., 2013). However, these studies (in addition to the Go/NoGo PCA studies cited above) illustrate that ERP morphology and the associated factor solutions can differ substantially between tasks and modalities, reflecting alternate cognitive demands and brain activity involved in task processing. These differences can provide useful insight; however, it is difficult to account for these variances without systematic investigation across a wide range of ERP factors, and to limit the scope of this thesis we focus, primarily, on simple auditory Go/NoGo tasks.

The Schema may be considered similar to early 'serial' processing accounts, such as the two-stage or four-stage models of information processing described by Dien et al. (2004). In brief,

the two-stage model refers to the perspective that ERP components reflect either stimulus or response processing; whereas the four-stage model separates stimulus processing into four phases: *stimulus registration*, *selection*, *identification*, and *categorisation*. These are both useful models that aid general ERP interpretation. In contrast, the Schema provides a more granular component-oriented interpretation of sequential processing in uncued auditory Go/NoGo tasks, extending from early stimulus registration to late post-response processing (e.g., performance evaluation and subsequent adjustments). In that sense, the Schema presents a broader and more pragmatic framework of sequential Go/NoGo processing, but it may not be as generalisable as other serial perspectives. The specificity of the Schema can be considered a strength, as it allows for a more complete data-driven conceptualisation and assessment of basic cognitive processing in a widely used research paradigm. Furthermore, the aim is that this holistic data-driven approach is developed and applied in concert with the broader research community to improve the field's understanding of Go/NoGo processing and provide a more rigorous delineation of ERP research outcomes. It is also important to note that a 'stage-based' perspective of cognition is not strictly adhered to in the interpretation of components or processes in the Schema, meaning that stimulus- and/or response-related processes may be considered to overlap in time or occur in parallel (*cf.* Sternberg, 1969).

1.5. Doctoral thesis: overview of research

The purpose of this doctoral thesis was to continue the development of the young adult Go/NoGo Sequential Processing Schema by clarifying the cognitive requirements and PCA-derived ERP components in the uncued auditory equiprobable Go/NoGo task. This was achieved over four separate studies (Chapters 2–5) that examined ERP and behavioural data collected from healthy young adults in two major experiments. In Experiment 1, data were acquired from participants while they completed both an auditory oddball and equiprobable Go/NoGo task, whereas in Experiment 2, similar data were acquired from a new sample of participants during auditory equiprobable and 'frequent Go' variants of the task.

Study 1 aimed to clarify the equiprobable Go/NoGo ERP component processing series through a comprehensive within-subjects comparison of the ERP factors and behaviour in the oddball and equiprobable tasks. The results in that study queried the role of the PN component in the Schema, which has important implications regarding the cognitive strategy that young adults use to process sensory information in Go/NoGo tasks. That query was investigated within-subjects in Study 2, which aimed to elucidate the early auditory processing in the equiprobable and 'frequent Go' tasks, by using cortical source analyses and shifts in stimulus probability to provide greater insight into the identity and function of PCA-derived Go/NoGo ERP factors.

Equiprobable Go/NoGo data from Experiments 1 and 2 were then combined to strengthen further analyses of the Go and NoGo ERP processing series in Study 3 and Study 4, respectively. Study 3 investigated stimulus- and response-locked averaging effects on Go ERP components to determine the role of the typical stimulus-locked factors associated with auditory equiprobable Go processing. Finally, Study 4 aimed to clarify the inhibitory demands in the auditory equiprobable task and to ultimately determine the relationship between the NoGo P3a and response inhibition.

The findings of this systematic research programme were expected to provide greater insight into auditory processing, particularly in simple equiprobable Go/NoGo tasks, while also promoting the development of the Schema and a range of psychophysiological theories relevant to common ERP components. The Schema was considered to be a useful framework for this research, and continuing its development was expected to improve our interpretation of discrete ERP outcomes, relative to other components (or psychophysiological events) in the broader Go/NoGo processing series. We predicted that this would clarify a range of ERP factors used to measure cognition in psychophysiology and help elucidate information processing in healthy young adults; this was expected to improve the holistic representation of Go/NoGo processing in the Schema, providing researchers with a more complete understanding of this popular research paradigm, and setting the stage for future studies mapping cognitive difficulties related to different psychopathologies.

References

Anderer, P., & Saletu, B. (2013). Fundamentals of low-resolution brain electromagnetic tomography. In E. Nofzinger, P. Maquet, & M. J. Thorpy (Eds.), *Neuroimaging of sleep and sleep disorders* (pp. 72–81). Cambridge University Press.

Anderson, N. E., Steele, V. R., Maurer, J. M., Bernat, E. M., & Kiehl, K. A. (2015). Psychopathy, attention, and oddball target detection: New insights from PCL-R facet scores. *Psychophysiology*, *52*(9), 1194–1204. https://doi.org/10.1111/psyp.12441

Asadzadeh, S., Rezaii, T. Y., Beheshti, S., Delpak, A., & Meshgini, S. (2020). A systematic review of EEG source localization techniques and their applications on diagnosis of brain abnormalities. *Journal of Neuroscience Methods*, *339*, Article 108740. https://doi.org/10.1016/j.jneumeth.2020.108740

Baghdadi, G., Towhidkhah, F., & Rostami, R. (2017). A mathematical and biological plausible model of decision-execution regulation in "Go/No-Go" tasks: Focusing on the fronto-striatal-thalamic pathway. *Computers in Biology and Medicine*, *86*, 113–128. https://doi.org/10.1016/j.compbiomed.2017.05.014

Bailey, K., Amlung, M. T., Morris, D. H., Price, M. H., Von Gunten, C., McCarthy, D. M., & Bartholow, B. D. (2016). Separate and joint effects of alcohol and caffeine on conflict monitoring and adaptation. *Psychopharmacology*, *233*(7), 1245–1255. https://doi.org/10.1007/s00213-016-4208-y

Baillet, S., Mosher, J. C., & Leahy, R. M. (2001). Electromagnetic brain mapping. *IEEE Signal Processing Magazine*, *18*(6), 14–30. https://doi.org/10.1109/79.962275

Banquet, J. P., Renault, B., & Lesèvre, N. (1981). Effect of task and stimulus probability on evoked potentials. *Biological Psychology*, *13*, 203–214. https://doi.org/10.1016/0301-0511(81)90036-3

Barratt, E. S. (1987). Impulsiveness and anxiety: Information processing and electroencephalograph topography. *Journal of Research Psychology, 21*, 453–463. https://doi.org/10.1016/0092-6566(87)90032-8

Barry, R. J., & De Blasio, F. M. (2013). Sequential processing in the equiprobable auditory Go/NoGo task: A temporal PCA study. *International Journal of Psychophysiology, 89*(1), 123–127. https://doi.org/10.1016/j.ijpsycho.2013.06.012

Barry, R. J., & De Blasio, F. M. (2015). Performance and ERP components in the equiprobable go/no-go task: Inhibition in children. *Psychophysiology, 52*(9), 1228–1237. https://doi.org/10.1111/psyp.12447

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2014). Caffeine effects on ERP components and performance in an equiprobable auditory Go/NoGo task. *Journal of Caffeine Research, 4*(3), 83–92. https://doi.org/10.1089/jcr.2014.0011

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2016). Sequential processing in younger and older

adults in the equiprobable auditory Go/NoGo task. *Clinical Neurophysiology*, *127*(5), 2273–2285. https://doi.org/10.1016/j.clinph.2016.02.010

Barry, R. J., De Blasio, F. M., Fogarty, J. S., & Karamacoska, D. (2016). ERP Go/NoGo condition effects are better detected with separate PCAs. *International Journal of Psychophysiology*, *106*, 50–64. https://doi.org/10.1016/j.ijpsycho.2016.06.003

Barry, R. J., & Rushby, J. A. (2006). An orienting reflex perspective on anteriorisation of the P3 of the event-related potential. *Experimental Brain Research*, *173*(3), 539–545. https://doi.org/10.1007/s00221-006-0590-8

Beauducel, A., & Debener, S. (2003). Misallocation of variance in event-related potentials: simulation studies on the effects of test power, topography, and baseline-to-peak versus principal component quantifications. *Journal of Neuroscience Methods*, *124*(1), 103–112. https://doi.org/10.1016/S0165-0270(02)00381-3

Beauducel, A., Debener, S., Brocke, B., & Kayser, J. (2000). On the reliability of augmenting/reducing: Peak amplitudes and principal component analysis of auditory evoked potentials. *Journal of Psychophysiology*, *14*(4), 226–240. https://doi.org/10.1027/0269-8803.14.4.226

Behforuzi, H., Feng, N. C., Billig, A. R., Ryan, E., Tusch, E. S., Holcomb, P., Mohammed, A. H., & Daffner, K. R. (2019). Markers of novelty processing in older adults are stable and reliable. *Frontiers in Aging Neuroscience*, *11*, Article 165. https://doi.org/10.3389/fnagi.2019.00165

Borchard, J. P., Barry, R. J., & De Blasio, F. M. (2015). Sequential processing in an auditory equiprobable Go/NoGo task with variable interstimulus interval. *International Journal of Psychophysiology*, *97*(2), 145–152. https://doi.org/10.1016/j.ijpsycho.2015.05.010

Brigham, J., Herning, R. I., & Moss, H. B. (1995). Event-related potentials and alpha synchronization in preadolescent boys at risk for psychoactive substance use. *Biological Psychiatry*, *37*(12), 834–846. https://doi.org/10.1016/0006-3223(94)00218-R

Brown, S. B., Van der Wee, N. J., Van Noorden, M. S., Giltay, E. J., & Nieuwenhuis, S. (2015). Noradrenergic and cholinergic modulation of late ERP responses to deviant stimuli. *Psychophysiology*, *52*(12), 1620–1631. https://doi.org/10.1111/psyp.12544

Browne, M. W. (2001). An overview of analytic rotation in exploratory factor analysis. *Multivariate Behavioral Research*, *36*(1), 111–150. https://doi.org/10.1207/S15327906MBR3601_05

Bruder, G., Kayser, J., Tenke, C., Amador, X., Friedman, M., Sharif, Z., & Gorman, J. (1999). Left temporal lobe dysfunction in schizophrenia: event-related potential and behavioral evidence from phonetic and tonal dichotic listening tasks. *Archives of General Psychiatry*, *56*(3), 267–276. https://doi.org/10.1001/archpsyc.56.3.267

Bruder, G. E., Kayser, J., Tenke, C. E., Leite, P., Schneier, F. R., Stewart, J. W., & Quitkin, F.

M. (2002). Cognitive ERPs in depressive and anxiety disorders during tonal and phonetic oddball tasks. *Clinical Electroencephalography*, *33*(3), 119–124. https://doi.org/10.1177/155005940203300308

Bruin, K. J., & Wijers, A. A. (2002). Inhibition, response mode, and stimulus probability: A comparative event-related potential study. *Clinical Neurophysiology*, *113*(7), 1172–1182. https://doi.org/10.1016/S1388-2457(02)00141-4

Camfield, D. A., Burton, T. K., De Blasio, F. M., Barry, R. J., & Croft, R. J. (2018). ERP components associated with an indirect emotional stop signal task in healthy and depressed participants. *International Journal of Psychophysiology*, *124*, 12–25. https://doi.org/10.1016/j.ijpsycho.2017.12.008

Cattell, R. B. (1966). The scree test for the number of factors. *Multivariate Behavioral Research*, *1*(2), 245–276. https://doi.org/10.1207/s15327906mbr0102_10

Cattell, R. B., & Jaspers, J. (1967). A general plasmode (No. 30-10-5-2) for factor analytic exercises and research. *Multivariate Behavioral Research Monographs, 67*(3), 1–212.

Cespón, J., & Carreiras, M. (2020). Is there electrophysiological evidence for a bilingual advantage in neural processes related to executive functions?. *Neuroscience and Biobehavioral Reviews*, *118*, 3

Chapman, R. M., & McCrary, J. W. (1995). EP component identification and measurement by principal components analysis. *Brain and Cognition*, *27*(3), 288–310. https://doi.org/10.1006/brcg.1995.1024

Chapman, R. M., McCrary, J. W., Gardner, M. N., Sandoval, T. C., Guillily, M. D., Reilly, L. A., & DeGrush, E. (2011). Brain ERP components predict which individuals progress to Alzheimer's disease and which do not. *Neurobiology of Aging*, *32*(10), 1742–1755. https://doi.org/10.1016/j.neurobiolaging.2009.11.010

Cheng, C. H., Tsai, H. Y., & Cheng, H. N. (2019). The effect of age on N2 and P3 components: A meta-analysis of Go/Nogo tasks. *Brain and Cognition*, *135*, 103574. https://doi.org/10.1016/j.bandc.2019.05.012

Cohen, M. X. (2014). Analyzing neural time series data: theory and practice. Cambridge, MA: MIT Press.

Cong, F. (2019). Blind Source Separation. In L. Hu & Z. Zhang (Eds.), *EEG Signal Processing and Feature Extraction* (pp. 117–140). Springer, Singapore.

Cong, F., Lin, Q. H., Astikainen, P., & Ristaniemi, T. (2014). How to validate similarity in linear transform models of event-related potentials between experimental conditions?. *Journal of Neuroscience Methods*, *236*, 76–85. https://doi.org/10.1016/j.jneumeth.2014.08.018

Crottaz-Herbette, S., & Ragot, R. (2000). Perception of complex sounds: N1 latency codes pitch and topography codes spectra. *Clinical Neurophysiology*, *111*(10), 1759–1766.

https://doi.org/10.1016/S1388-2457(00)00422-3

Curran, T., & Dien, J. (2003). Differentiating amodal familiarity from modality-specific memory processes: An ERP study. *Psychophysiology*, *40*(6), 979–988. https://doi.org/10.1111/1469-8986.00116

Dalbokova, D., Gille, H. G., & Ullsperger, P. (1990). Amplitude variations in P300 component due to unpredictable stepwise change of stimulus probability. *International Journal of Psychophysiology*, *10*(1), 33–38. https://doi.org/10.1016/0167-8760(90)90042-c

Delplanque, S., Silvert, L., Hot, P., & Sequeira, H. (2005). Event-related P3a and P3b in response to unpredictable emotional stimuli. *Biological Psychology*, *68*(2), 107–120. https://doi.org/10.1016/j.biopsycho.2004.04.006

Deveney, C. M., & Deldin, P. J. (2004). Memory of faces: a slow wave ERP study of major depression. *Emotion*, *4*(3), 295–304. https://doi.org/10.1037/1528-3542.4.3.295

De Zorzi, L., Robin, M. S., Honoré, J., Bubrovszky, M., Vaiva, G., & Sequeira, H. (2020). Depression restricts visual capture and promotes the perception of negative information. *Biological Psychology*, *154*, 107923. https://doi.org/10.1016/j.biopsycho.2020.107923

Dien, J. (1998). Addressing misallocation of variance in principal components analysis of event-related potentials. *Brain Topography*, *11*(1), 43–55. https://doi.org/10.1023/A

Dien, J. (2006). Progressing towards a consensus on PCA of ERPs. *Clinical Neurophysiology*, *117*(3), 699–702. https://doi.org/10.1016/j.clinph.2005.09.029

Dien, J. (2010). Evaluating two-step PCA of ERP data with geomin, infomax, oblimin, promax, and varimax rotations. *Psychophysiology*, *47*(1), 170–183. https://doi.org/10.1111/j.1469-8986.2009.00885.x

Dien, J. (2014, August 7). *Re: How Are Subject, Electrode and Condition Layered in the PCA Sub-Panes?* [Online forum post]. SourceForge. http://sourceforge.net/p/erppcatoolkit/discussion/767176/thread/6523430c/.

Dien, J., Beal, D. J., & Berg, P. (2005). Optimizing principal components analysis of event-related potentials: matrix type, factor loading weighting, extraction, and rotations. *Clinical Neurophysiology*, *116*(8), 1808–1825. https://doi.org/10.1016/j.clinph.2004.11.025

Dien, J., & Frishkoff, G. A. (2005). Introduction to principal components analysis of event-related potentials. In T. Handy (Ed.), *Event-related potentials: A methods handbook* (pp. 189–208). Cambridge, MA: MIT Press.

Dien, J., Spencer, K. M., & Donchin, E. (2004). Parsing the late positive complex: mental chronometry and the ERP components that inhabit the neighborhood of the P300. *Psychophysiology*, *41*(5), 665–678. https://doi.org/10.1111/j.1469-8986.2004.00193.x

Dimigen, O., Valsecchi, M., Sommer, W., & Kliegl, R. (2009). Human microsaccade-related visual brain responses. *Journal of Neuroscience*, *29*(39), 12321–12331.

https://doi.org/10.1523/JNEUROSCI.0911-09.2009

Donchin, E. (1966). A multivariate approach to the analysis of average evoked potentials. *IEEE Transactions of Biomedical Engineering*, *13*, 131–139.

Donchin, E. (1969). Data analysis techniques in average evoked potential research. In E. Donchin & D. B. Lindsley (Eds.), *Average evoked potentials: Methods, results, and evaluations* (p. 199–236). US National Aeronautics and Space Administration. https://doi.org/10.1037/13016-005

Donchin, E., & Heffley, E. F. (1978). Multivariate analysis of event-related potential data: A tutorial review. In D. A. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (pp. 555–572). Washington, DC: U.S. Government Printing Office.

Donchin, E., Ritter. W., & McCallum. W. C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In E. Callaway, P. Tueting, & S. H. Coslow (Eds.), *Event-related brain potentials in man* (pp. 349–411). New York: Academic Press.

Duncan-Johnson, C. C., & Donchin, E. (1977). On quantifying surprise: The variation of event-related potentials with subjective probability. *Psychophysiology*, *14*(5), 456–467. https://doi.org/10.1111/j.1469-8986.1977.tb01312.x

Eliades, S. J., Crone, N. E., Anderson, W. S., Ramadoss, D., Lenz, F. A., & Boatman-Reich, D. (2014). Adaptation of high-gamma responses in human auditory association cortex. *Journal of Neurophysiology*, *112*(9), 2147–2163. https://doi.org/10.1152/jn.00207.2014

Fabiani, M., Gratton, G., Karis, D., & Donchin, E. (1987). Definition, identification, and reliability of measurement of the P300 component of the event-related brain potential. *Advances in psychophysiology*, *2*, 1–78.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica*, *101*(2–3), 267–291. https://doi.org/10.1016/S0001-6918(99)00008-6

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (2002). Inhibition-related ERP components: Variation with modality, age, and time-on-task. *Journal of Psychophysiology*, *16*(3), 167–175. https://doi.org/10.1027//0269-8803.16.3.167

Falkenstein, M., Koshlykova, N. a, Kiroj, V. N., Hoormann, J., & Hohnsbein, J. (1995). Late ERP components in visual and auditory Go/Nogo tasks. *Electroencephalography and Clinical Neurophysiology*, *96*(94), 36–43. https://doi.org/10.1016/0013-4694(94)00182-K

Fava, J. L., & Velicer, W. F. (1992). The effects of overextraction on factor and component analysis. *Multivariate Behavioral Research*, *27*(3), 387–415. https://doi.org/10.1207/s15327906mbr2703_5

Fava, J. L., & Velicer, W. F. (1996). The effects of underextraction in factor and component analyses. *Educational and Psychological Measurement*, *56*(6), 907–929. https://doi.org/10.1177/0013164496056006001

Fink, B. C., Steele, V. R., Maurer, M. J., Fede, S. J., Calhoun, V. D., & Kiehl, K. A. (2016). Brain potentials predict substance abuse treatment completion in a prison sample. *Brain and Behavior*, *6*(8), Article e00501. https://doi.org/10.1002/brb3.501

Fogarty, J. S., Barry, R. J., De Blasio, F. M., & Steiner, G. Z. (2018). ERP components and behavior in the auditory equiprobable go/no-go task: Inhibition in young adults. *Psychophysiology*, *55*(7), Article e13065. https://doi.org/10.1111/psyp.13065

Friedman, D. (1984). P300 and slow wave: the effects of reaction time quartile. *Biological Psychology*, *18*(1), 49–71. https://doi.org/10.1016/0301-0511(84)90028-0

Fuchs, M., Wagner, M., Köhler, T., & Wischmann, H. A. (1999). Linear and nonlinear current density reconstructions. *Journal of Clinical Neurophysiology*, *16*(3), 267–295. https://doi.org/10.1097/00004691-199905000-00006

Fuchs, M., Wischmann, H. A., & Wagner, M. (1994). Generalized minimum norm least squares reconstruction algorithms. *ISBET Newsletter*, *5*, 8–1.

García-Larrea, L., Lukaszewicz, A. C., & Mauguire, F. (1992). Revisiting the oddball paradigm. Non-target vs neutral stimuli and the evaluation of ERP attentional effects. *Neuropsychologia*, *30*(8), 723–741. https://doi.org/10.1016/0028-3932(92)90042-K

Goldstein, A., Spencer, K. M., & Donchin, E. (2002). The influence of stimulus deviance and novelty on the P300 and novelty P3. *Psychophysiology*, *39*(6), 781–790.

Gomez, P., Ratcliff, R., & Perea, M. (2007). A model of the go/no go task. *Journal of Experimental Psychology*, *136*(3), 389–413. https://doi.org/10.1037/0096-3445.136.3.389.A

Grech, R., Cassar, T., Muscat, J., Camilleri, K. P., Fabri, S. G., Zervakis, M., Xanthopoulos, P., Sakkalis, V., & Vanrumste, B. (2008). Review on solving the inverse problem in EEG source analysis. *Journal of Neuroengineering and Rehabilitation*, *5*(1), Article 25. https://doi.org/10.1186/1743-0003-5-25

Griskova-Bulanova, I., Griksiene, R., Voicikas, A., & Ruksenas, O. (2016). Go and NoGo: modulation of electrophysiological correlates by female sex steroid hormones. *Psychopharmacology*, *233*, 2607–2615. https://doi.org/10.1007/s00213-016-4311-0

Haalman, I., & Vaadia, E. (1997). Dynamics of neuronal interactions: relation to behavior, firing rates, and distance between neurons. *Human Brain Mapping*, *5*(4), 249–253. https://doi.org/10.1002/(SICI)1097-0193(1997)5:4<249::AID-HBM8>3.0.CO;2-3

Halder, T., Talwar, S., Jaiswal, A. K., & Banerjee, A. (2019). Quantitative evaluation in estimating sources underlying brain oscillations using current source density methods and beamformer approaches. *Eneuro*, *6*(4), 1–14.

https://doi.org/10.1523/ENEURO.0170-19.2019

Handy, T. C. (2005). *Event-related potentials: A methods handbook*. Cambridge, MA: MIT Press.

Hayton, J. C., Allen, D. G., & Scarpello, V. (2004). Factor retention decisions in exploratory factor analysis: A tutorial on parallel analysis. *Organizational Research Methods*, *7*(2), 191–205. https://doi.org/10.1177/1094428104263675

He, B., & Ding, L. (2013) Electrophysiological Mapping and Neuroimaging. In B. He (Ed.) *Neural Engineering* (pp. 499–543). Boston, MA: Springer. https://doi.org/10.1007/978-1-4614-5227-0_12

He, J. L., Fuelscher, I., Coxon, J., Barhoun, P., Parmar, D., Enticott, P. G., & Hyde, C. (2018). Impaired motor inhibition in developmental coordination disorder. *Brain and Cognition*, *127*, 23–33. https://doi.org/10.1016/j.bandc.2018.09.002

Heinrich, S. P., & Bach, M. (2008). Signal and noise in P300 recordings to visual stimuli. *Documenta Ophthalmologica*, *117*(1), 73–83. https://doi.org/10.1007/s10633-007-9107-4

Hepsomali, P., Hadwin, J. A., Liversedge, S. P., Degno, F., & Garner, M. (2019). The impact of cognitive load on processing efficiency and performance effectiveness in anxiety: evidence from event-related potentials and pupillary responses. *Experimental Brain Research*, *237*(4), 897–909. https://doi.org/10.1007/s00221-018-05466-y

Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science*, *182*(4108), 177–180. https://doi.org/10.1126/science.182.4108.177

Hoormann, J., Falkenstein, M., Schwarzenau, P., & Hohnsbein, J. (1998). Methods for the quantification and statistical testing of ERP differences across conditions. *Behavior Research Methods, Instruments, & Computers*, *30*(1), 103–109. https://doi.org/10.3758/BF03209420

Horat, S. K., Herrmann, F. R., Favre, G., Terzis, J., Debatisse, D., Merlo, M., & Missonnier, P. (2016). Assessment of mental workload: A new electrophysiological method based on intra-block averaging of ERP amplitudes. *Neuropsychologia*, *82*, 11–17. https://doi.org/10.1016/j.neuropsychologia.2015.12.013

Horn, J. L. (1965). A rationale and test for the number of factors in factor analysis. *Psychometrika*, *30*(2), 179–185. https://doi.org/10.1007/BF02289447

Howell, D. R., Meehan, W. P., 3rd, Barber Foss, K. D., Reches, A., Weiss, M., & Myer, G. D. (2018). Reduced dual-task gait speed is associated with visual Go/No-Go brain network activation in children and adolescents with concussion. *Brain Injury*, *32*(9), 1129–1134. https://doi.org/10.1080/02699052.2018.1482424

Hoyniak, C. P., & Petersen, I. T. (2019). A meta-analytic evaluation of the N2 component as an

endophenotype of response inhibition and externalizing psychopathology in childhood. *Neuroscience and Biobehavioral Reviews*, *103*, 200–215. https://doi.org/10.1016/j.neubiorev.2019.06.011

Hull, J., & Harsh, J. (2001). P300 and sleep-related positive waveforms (P220, P450, and P900) have different determinants. *European Sleep Research Society*, *10*, 9–17. https://doi.org/10.1046/j.1365-2869.2001.00238.x

Ibrahim, I. A., Ting, H. N., & Moghavvemi, M. (2018). The effects of audio stimuli on auditory-evoked potential in normal hearing Malay adults. *International Journal of Health Sciences*, *12*(5), 25–34.

Jatoi, M. A., Kamel, N., Malik, A. S., & Faye, I. (2014). EEG based brain source localization comparison of sLORETA and eLORETA. *Australasian Physical & Engineering Sciences in Medicine*, *37*(4), 713–721. https://doi.org/10.1007/s13246-014-0308-3

Kaiser, H. F. (1960). The application of electronic computers to factor analysis. *Educational and Psychological Measurement, 20,* 141–151. https://doi.org/10.1177/001316446002000116

Kałamała, P., Szewczyk, J., Senderecka, M., & Wodniecka, Z. (2018). Flanker task with equiprobable congruent and incongruent conditions does not elicit the conflict N2. *Psychophysiology*, *55*(2), Article e12980. https://doi.org/10.1111/psyp.12980

Kamarajan, C., Porjesz, B., Jones, K. A., Choi, K., Chorlian, D. B., Padmanabhapillai, A., Rangaswamy, M., Stimus, A. T., & Begleiter, H. (2005). Alcoholism is a disinhibitory disorder: Neurophysiological evidence from a Go/No-Go task. *Biological Psychology*, *69*(3), 353–373. https://doi.org/10.1016/j.biopsycho.2004.08.004

Kamp, S. M. (2020). Preceding stimulus sequence effects on the oddball-P300 in young and healthy older adults. *Psychophysiology*, Article e13593. https://doi.org/10.1111/psyp.13593

Kardos, Z., Kóbor, A., & Molnár, M. (2020). Accurate response selection and inhibition in healthy aging: An event-related potential study. *Psychology and Aging*, *35*(5), 720–728. https://doi.org/10.1037/pag0000466

Kayser, J., Fong, R., Tenke, C. E., & Bruder, G. E. (2003). Event-related brain potentials during auditory and visual word recognition memory tasks. *Cognitive Brain Research*, *16*(1), 11–25. https://doi.org/10.1016/S0926-6410(02)00205-7

Kayser, J., & Tenke, C. E. (2003). Optimizing PCA methodology for ERP component identification and measurement: Theoretical rationale and empirical evaluation. *Clinical Neurophysiology*, *114*(12), 2307–2325. https://doi.org/10.1016/S1388-2457(03)00241-4

Kayser, J., & Tenke, C. E. (2005). Trusting in or breaking with convention: towards a renaissance of principal components analysis in electrophysiology. *Clinical Neurophysiology*, *116*(8), 1747–1753. https://doi.org/10.1016/j.clinph.2005.03.020

Kayser, J., & Tenke, C. E. (2006a). Consensus on PCA for ERP data, and sensibility of unrestricted solutions. *Clinical Neurophysiology*, *117*(3), 703–707. https://doi.org/10.1016/j.clinph.2005.11.015

Kayser, J., & Tenke, C. E. (2006b). Principal components analysis of Laplacian waveforms as a generic method for identifying ERP generator patterns: I. Evaluation with auditory oddball tasks. *Clinical Neurophysiology*, *117*(2), 348–368. https://doi.org/10.1016/j.clinph.2005.08.034

Kayser, J., & Tenke, C. E. (2006c). Principal components analysis of Laplacian waveforms as a generic method for identifying ERP generator patterns: II. Adequacy of low-density estimates. *Clinical Neurophysiology*, *117*(2), 369–380. https://doi.org/10.1016/j.clinph.2005.08.033

Kayser, J., Tenke, C. E., & Bruder, G. E. (1998). Dissociation of brain ERP topographies for tonal and phonetic oddball tasks. *Psychophysiology*, *35*(5), 576–590. https://doi.org/10.1017/S0048577298970214

Kayser, J., Tenke, C. E., Gil, R., & Bruder, G. E. (2010). ERP generator patterns in schizophrenia during tonal and phonetic oddball tasks: effects of response hand and silent count. *Clinical EEG and Neuroscience*, *41*(4), 184–195. https://doi.org/10.1177/155005941004100405

Kayser, J., Tenke, C. E., Kroppmann, C. J., Alschuler, D. M., Fekri, S., Ben-David, S., Corcoran, C. M., & Bruder, G. E. (2014). Auditory event-related potentials and alpha oscillations in the psychosis prodrome: neuronal generator patterns during a novelty oddball task. *International Journal of Psychophysiology*, *91*(2), 104–120. https://doi.org/10.1016/j.ijpsycho.2013.12.003

Keskin-Ergen, Y., Tükel, R., Aslantaş-Ertekin, B., Ertekin, E., Oflaz, S., & Devrim-Üçok, M. (2014). N2 and P3 potentials in early-onset and late-onset patients with obsessive-compulsive disorder. *Depression and Anxiety*, *31*(12), 997–1006. https://doi.org/10.1002/da.22212

Key, A. P., & Yoder, P. J. (2013). Equiprobable and oddball paradigms: two approaches for documenting auditory discrimination. *Developmental Neuropsychology, 38*(6), 402–17. https://doi.org/10.1080/87565641.2012.718819

Key, A. P., Yoder, P. J., & Stone, W. L. (2016). Consonant differentiation mediates the discrepancy between non-verbal and verbal abilities in children with ASD. *Journal of Intellectual Disability Research*, *60*(5), 478–490. https://doi.org/10.1111/jir.12286

Kieffer, K. M. (1999). An Introductory Primer on the Appropriate Use of Exploratory and Confirmatory Factor Analysis. *Research in the Schools*, *6*(2), 75–92.

Kim, S. H., Grammer, J., Benrey, N., Morrison, F., & Lord, C. (2018). Stimulus processing and error monitoring in more-able kindergarteners with autism spectrum disorder: a short

review and a preliminary Event-Related Potentials study. *The European Journal of Neuroscience*, *47*(6), 556–567. https://doi.org/10.1111/ejn.13580

Koenig, T., Stein, M., Grieder, M., & Kottlow, M. (2014). A tutorial on data-driven methods for statistically assessing ERP topographies. *Brain Topography*, *27*(1), 72–83. https://doi.org/10.1007/s10548-013-0310-1

Koerner, T. K., & Zhang, Y. (2015). Effects of background noise on inter-trial phase coherence and auditory N1–P2 responses to speech stimuli. *Hearing Research*, *328*, 113–119. https://doi.org/10.1016/j.heares.2015.08.002

Kotchoubey, B., & Pavlov, Y. G. (2019). A Signature of Passivity? An Explorative Study of the N3 Event- Related Potential Component in Passive Oddball Tasks. *Frontiers in Neuroscience*, *13*, 365. https://doi.org/10.3389/fnins.2019.00365

Landa, L., Krpoun, Z., Kolerova, M., & Kasparek, T. (2014). Event-related potentials and their applications. *Activitas Nervosa Superior*, *56*(1), 17–23. https://doi.org/10.1007/BF03379603

Lavric, A., Pizzagalli, D. A., & Forstmeier, S. (2004). When 'go'and 'nogo'are equally frequent: ERP components and cortical tomography. *European Journal of Neuroscience*, *20*(9), 2483–2488. https://doi.org/10.1111/j.1460-9568.2004.03683.x

Le, T. M., Zhang, S., Zhornitsky, S., Wang, W., & Li, C. R. (2020). Neural correlates of reward-directed action and inhibition of action. *Cortex*, *123*, 42–56. https://doi.org/10.1016/j.cortex.2019.10.007

Lehmann, D., & Skrandies, W. (1980). Reference-free identification of components of checkerboard-evoked multichannel potential fields. *Electroencephalography and Clinical Neurophysiology*, *48*(6), 609–621. https://doi.org/10.1016/0013-4694(80)90419-8

Liebenthal, E., Ellingson, M. L., Spanaki, M. V., Prieto, T. E., Ropella, K. M., & Binder, J. R. (2003). Simultaneous ERP and fMRI of the auditory cortex in a passive oddball paradigm. *NeuroImage*, *19*(4), 1395–1404. https://doi.org/10.1016/S1053-8119(03)00228-3

Liem, F., Zaehle, T., Burkhard, A., Jäncke, L., & Meyer, M. (2012). Cortical thickness of supratemporal plane predicts auditory N1 amplitude. *Neuroreport*, *23*(17), 1026–1030. https://doi.org/10.1097/WNR.0b013e32835abc5c

Lin, M. Y., & Cheng, C. H. (2020). Effect of Age in Auditory Go/No-Go Tasks: A Magnetoencephalographic Study. *Brain Sciences*, *10*(10), 667. https://doi.org/10.3390/brainsci10100667

Llinás, R. R. (1988). The intrinsic electrophysiological properties of mammalian neurons: insights into central nervous system function. *Science*, *242*(4886), 1654–1664. https://doi.org/10.1126/science.3059497

Low, K. A. & Miller, J. (1999). The usefulness of partial information: effects of go probability in the choice/Nogo task. *Psychophysiology*, *36*(3), 288–297. https://doi.org/10.1017/S0048577299980332

Lubman, D. I., Allen, N. B., Peters, L. A., & Deakin, J. W. (2007). Electrophysiological evidence of the motivational salience of drug cues in opiate addiction. *Psychological Medicine*, *37*(8), 1203–1209. https://doi.org/10.1017/S0033291707009932

Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.

Macatee, R. J., Albanese, B. J., Clancy, K., Allan, N. P., Bernat, E. M., Cougle, J. R., & Schmidt, N. B. (2018). Distress intolerance modulation of neurophysiological markers of cognitive control during a complex go/no-go task. *Journal of Abnormal Psychology*, *127*(1), 12–29. https://doi.org/10.1037/abn0000323

Makeig, S., Jung, T. P., Bell, A. J., Ghahremani, D., & Sejnowski, T. J. (1997). Blind separation of auditory event-related brain responses into independent components. *Proceedings of the National Academy of Sciences*, *94*(20), 10979–10984. https://doi.org/10.1073/pnas.94.20.10979

Makeig, S., Jung, T. P., Ghahremani, D., & Sejnowski, T. J. (1996). Independent component analysis of simulated ERP data. In T. Nakada (Ed.), *Integrated human brain science: Theory, method, applications (music)*. Elsevier.

Maldonado, T., Orr, J. M., Goen, J., & Bernard, J. A. (2020). Age Differences in the Subcomponents of Executive Functioning. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *75*(6), 31–55. https://doi.org/10.1093/geronb/gbaa005

Marsh, H. W., Muthén, B., Asparouhov, T., Lüdtke, O., Robitzsch, A., Morin, A. J., & Trautwein, U. (2009). Exploratory structural equation modeling, integrating CFA and EFA: Application to students' evaluations of university teaching. *Structural Equation Modeling: A Multidisciplinary Journal*, *16*(3), 439–476. https://doi.org/10.1080/10705510903008220

Matsuda, I., & Nittono, H. (2015). Motivational significance and cognitive effort elicit different late positive potentials. *Clinical Neurophysiology*, *126*(2), 304–313. https://doi.org/10.1016/j.clinph.2014.05.030

Mecklinger, A., Kramer, A. F., & Strayer, D. L. (1992). Event related potentials and EEG components in a semantic memory search task. *Psychophysiology*, *29*(1), 104–119. https://doi.org/10.1111/j.1469-8986.1992.tb02021.x

Melynyte, S., Ruksenas, O., & Griskova-Bulanova, I. (2017). Sex differences in equiprobable auditory Go/NoGo task: Effects on N2 and P3. *Experimental Brain Research*, *235*, 1565–1574. http://doi. org/10.1007/s00221-017-4911-x

Michel, C. M., & Brunet, D. (2019). EEG source imaging: a practical review of the analysis steps. *Frontiers in Neurology*, *10*, Article 325. https://doi.org/10.3389/fneur.2019.00325

Michel, C. M., Murray, M. M., Lantz, G., Gonzalez, S., Spinelli, L., & de Peralta, R. G. (2004). EEG source imaging. *Clinical Neurophysiology*, *115*(10), 2195–2222. https://doi.org/10.1016/j.clinph.2004.06.001

Mørup, M., Hansen, L. K., Herrmann, C. S., Parnas, J., & Arnfred, S. M. (2006). Parallel factor analysis as an exploratory tool for wavelet transformed event-related EEG. *NeuroImage*, *29*(3), 938–947. https://doi.org/10.1016/j.neuroimage.2005.08.005

Mudar, R. A., Nguyen, L. T., Eroh, J., Chiang, H. S., Rackley, A., & Chapman, S. B. (2019). Event-related neural oscillation changes following reasoning training in individuals with Mild Cognitive Impairment. *Brain Research*, *1704*, 229–240. https://doi.org/10.1016/j.brainres.2018.10.017

Mulaik, S. A. (2005). Looking back on the indeterminacy controversies in factor analysis. In A. Maydeu-Olivares & J. J. McArdle (Eds.), *Contemporary psychometrics: A festschrift for Roderick P. McDonald* (pp. 173–206). Mahwah, NJ: Erlbaum.

Näätänen, R. (1982). Processing negativity: An evoked-potential reflection of selective attention. *Psychological Bulletin*, *92*(3), 605–640. https://doi.org/10.1037/0033-2909.92.3.605

Näätänen, R. (1990). The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. *Behavioral and Brain Sciences*, *13*(2), 201–233. https://doi.org/10.1017/S0140525X00078407

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology*, *24*(4), 375–425. https://doi.org/10.1111/j.1469-8986.1987.tb00311.x

Nakajima, Y., & Imamura, N. (2000). Probability and interstimulus interval effects on the N140 and the P300 components of somatosensory ERPs. *International Journal of Neuroscience*, *104*(1), 75–91. https://doi.org/10.3109/00207450009035010

Nakata, H., Inui, K., Wasaka, T., Tamura, Y., Kida, T., & Kakigi, R. (2005). Effects of ISI and stimulus probability on event-related go/nogo potentials after somatosensory stimulation. *Experimental Brain Research*, *162*(3), 293–299. https://doi.org/10.1007/s00221-004-2195-4

Nanda, P., Morris, A., Kelemen, J., Yang, J., & Wiest, M. C. (2020). Evoked Frontal and Parietal Field Potential Signatures of Target Detection and Response Inhibition in Rats Performing an Equiprobable Auditory Go/No-Go Task. *eNeuro*, *7*(1), ENEURO.0055-19.2019. https://doi.org/10.1523/ENEURO.0055-19.2019

Nguyen, L. T., Mudar, R. A., Chiang, H. S., Schneider, J. M., Maguire, M. J., Kraut, M. A., & Hart, J., Jr (2017). Theta and Alpha Alterations in Amnestic Mild Cognitive Impairment

in Semantic Go/NoGo Tasks. *Frontiers in Aging Neuroscience*, *9*, 160. https://doi.org/10.3389/fnagi.2017.00160

Nunez, P. L. & Srinivasan, R. (2006). *Electric fields of the brain: The neurophysics of EEG (2nd ed.)*. NY: Oxford University Press.

Ouyang, G., Herzmann, G., Zhou, C., & Sommer, W. (2011). Residue Iteration Decomposition (RIDE): A new method to separate ERP components on the basis of latency variability in single trials. *Psychophysiology*, *48*(12), 1631–1647. https://doi.org/10.1111/j.1469-8986.2011.01269.x

Paiva, T. O., Almeida, P. R., Ferreira-Santos, F., Vieira, J. B., Silveira, C., Chaves, P. L., Barbosa, F., & Marques-Teixeira, J. (2016). Similar sound intensity dependence of the N1 and P2 components of the auditory ERP: Averaged and single trial evidence. *Clinical Neurophysiology*, *127*(1), 499–508. https://doi.org/10.1016/j.clinph.2015.06.016

Pascual-Marqui, R. D. (1999). Review of methods for solving the EEG inverse problem. *International Journal of Bioelectromagnetism*, *1*(1), 75–86.

Pascual-Marqui, R. D. (2002). Standardised low resolution brain electromagnetic tomography (sLORETA): technical details. *Methods & Findings in Experimental & Clinical Pharmacology*, *24* (Suppl. D), 5–12.

Pascual-Marqui, R. D. (2007). Discrete, 3D distributed, linear imaging methods of electric neuronal activity. Part 1: Exact, zero error localization. *arXiv*. https://arxiv.org/abs/0710.3341

Pascual-Marqui, R. D. (2009). Theory of the EEG inverse problem. In S. Tong & N. Thakor (Eds.). *Quantitative EEG analysis: methods and clinical applications* (pp. 121–140). Boston: Artech House

Pascual-Marqui, R. D., Esslen, M., Kochi, K., & Lehmann, D. (2002). Functional imaging with low-resolution brain electromagnetic tomography (LORETA): a review. *Methods & Findings in Experimental & Clinical Pharmacology*, *24*(Suppl C), 91–95.

Pascual-Marqui, R. D., Lehmann, D., Koukkou, M., Kochi, K., Anderer, P., Saletu, B., Tanaka, H., Hirata, K., John, E. R., Prichep, L., Biscay-Lirio, R., & Kinoshita, T. (2011). Assessing interactions in the brain with exact low-resolution electromagnetic tomography. *Philosophical Transactions of the Royal Society A*, *369*(1952), 3768–3784. https://doi.org/10.1098/rsta.2011.0081

Pfefferbaum, A., & Ford, J. M. (1988). ERPs to stimuli requiring response production and inhibition: effects of age, probability and visual noise. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *71*(1), 55–63. https://doi.org/10.1016/0168-5597(88)90019-6

Pfefferbaum, A., Ford, J. M., Weller, B. J., & Kopell, B. S. (1985). ERPs to response production

and inhibition. *Electroencephalography and Clinical Neurophysiology*, *60*(5), 423–434. https://doi.org/10.1016/0013-4694(85)91017-X

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., Jr., Miller, G. A., Ritter, W., Ruchkin, D. S., Rugg, M. D., & Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. *Psychophysiology*, *37*(2), 127–152. https://doi.org/10.1111/1469-8986.3720127

Piispala, J., Kallio, M., Bloigu, R., & Jansson-Verkasalo, E. (2016). Delayed N2 response in Go condition in a visual Go/Nogo ERP study in children who stutter. *Journal of Fluency Disorders*, *48*, 16–26. https://doi.org/10.1016/j.jfludis.2016.02.001

Piispala, J., Määttä, S., Pääkkönen, A., Bloigu, R., Kallio, M., & Jansson-Verkasalo, E. (2017). Atypical brain activation in children who stutter in a visual Go/Nogo task: An ERP study. *Clinical Neurophysiology*, *128*(1), 194–203. https://doi.org/10.1016/j.clinph.2016.11.006

Polich, J., Eischen, S. E., & Collins, G. E. (1994). P300 from a single auditory stimulus. *Electroencephalography and Clinical Neurophysiology/ Evoked Potentials*, *92*(3), 253–261. https://doi.org/10.1016/0168-5597(94)90068-X

Polich, J., & Margala, C. (1997). P300 and probability: Comparison of oddball and single-stimulus paradigms. *International Journal of Psychophysiology*, *25*(2), 169–176. https://doi.org/10.1016/S0167-8760(96)00742-8

Ponomarev, V. A., Pronina, M. V., & Kropotov, Y. D. (2019). Latent Components of Event-Related Potentials in a Visual Cued Go/NoGo Task. *Human Physiology*, *45*(5), 474-482. https://doi.org/10.1134/S0362119719050141

Portella, C., Machado, S., Paes, F., Cagy, M., Sack, A. T., Sandoval-Carrillo, A., Salas-Pacheco, J. S., Silva, A. C., Piedade, R., Ribeiro, P., Nardi, A. E., & Arias-Carrión, O. (2014). Differences in early and late stages of information processing between slow versus fast participants. *International Archives of Medicine*, *7*(1), 1–8. https://doi.org/10.1186/1755-7682-7-49

Proverbio, A. M., Orlandi, A., & Pisanu, F. (2016). Brain processing of consonance/dissonance in musicians and controls: a hemispheric asymmetry revisited. *The European Journal of Neuroscience*, *44*(6), 2340–2356. https://doi.org/10.1111/ejn.13330

Quinzi, F., Perri, R. L., Berchicci, M., Bianco, V., Pitzalis, S., Zeri, F., & Di Russo, F. (2018). Weak proactive cognitive/motor brain control accounts for poor children's behavioral performance in speeded discrimination tasks. *Biological Psychology*, *138*, 211–222. https://doi.org/10.1016/j.biopsycho.2018.08.014

Rasmusson, D. X., & Allen, J. D. (1994). Intertarget interval does not affect P300 within oddball series. *International Journal of Psychophysiology*, *17*(1), 57–63. https://doi.org/10.1016/0167-8760(94)90055-8

Ravden, D., & Polich, J. (1998). Habituation of P300 from visual stimuli. *International Journal of Psychophysiology*, *30*(3), 359–365. https://doi.org/10.1016/s0167-8760(98)00039-7

Roberts, L. E., Rau, H., Lutzenberger, W., & Birbaumer, N. (1994). Mapping P300 waves onto inhibition: Go/NoGo discrimination. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *92*(1), 44–55. https://doi.org/10.1016/0168-5597(94)90006-X

Rockstroh, B., Müller, M., Heinz, A., Wagner, M., Berg, P., & Elbert, T. (1996). Modulation of auditory responses during oddball tasks. *Biological Psychology*, *43*(1), 41–55. https://doi.org/10.1016/0301-0511(95)05175-9

Rogers, L. J. (1991). Determination of the number and waveshapes of event related potential components using comparative factor analysis. *International Journal of Neuroscience*, *56*(1–4), 219–246. https://doi.org/10.3109/00207459108985421

Rüsseler, J., Johannes, S., Kowalczuk, J., Wieringa, B. M., & Münte, T. F. (2003). Developmental dyslexics show altered allocation of attention in visual classification tasks. *Acta Neurologica Scandinavica*, *107*(1), 22–30. https://doi.org/10.1034/j.1600-0404.2003.02060.x

Salisbury, D. F., Collins, K. C., & McCarley, R. W. (2010). Reductions in the N1 and P2 auditory event-related potentials in first-hospitalized and chronic schizophrenia. *Schizophrenia Bulletin*, *36*(5), 991–1000. https://doi.org/10.1093/schbul/sbp003

Sams, M., Alho, K., & Näätänen, R. (1983). Sequential effects on the ERP in discriminating two stimuli. *Biological Psychology*, *17*(1), 41–58. https://doi.org/10.1016/0301-0511(83)90065-0

Sass, D. A., & Schmitt, T. A. (2010). A comparative investigation of rotation criteria within exploratory factor analysis. *Multivariate Behavioral Research*, *45*(1), 73–103. https://doi.org/10.1080/00273170903504810

Scharf, F., & Nestler, S. (2018a). Exploratory structural equation modelling for event-related potential data—An all-in-one approach? *Psychophysiology*, *56*(3), 1–19. https://doi.org/10.1111/psyp.13303

Scharf, F., & Nestler, S. (2018b). Principles behind variance misallocation in temporal exploratory factor analysis for ERP data: Insights from an inter-factor covariance decomposition. *International Journal of Psychophysiology*, *128*, 119–136. https://doi.org/10.1016/j.ijpsycho.2018.03.019

Scharf, F., & Nestler, S. (2019). A comparison of simple structure rotation criteria in temporal exploratory factor analysis for event-related potential data. *Methodology*, 15, 43–60. https://doi.org/10.1027/1614-2241/a000175

Schmitt, T. A., & Sass, D. A. (2011). Rotation criteria and hypothesis testing for exploratory factor analysis: Implications for factor pattern loadings and interfactor correlations.

Educational and Psychological Measurement, *71*(1), 95–113. https://doi.org/10.1177/0013164410387348

Siegel, S. J., Connolly, P., Liang, Y., Lenox, R. H., Gur, R. E., Bilker, W. B., Kanes, S. J., & Turetsky, B. I. (2003). Effects of strain, novelty, and NMDA blockade on auditory-evoked potentials in mice. *Neuropsychopharmacology*, *28*(4), 675–682. https://doi.org/10.1038/sj.npp.1300087

Soufflet, L., & Boeijinga, P. H. (2005). Linear inverse solutions: simulations from a realistic head model in MEG. *Brain Topography*, *18*(2), 87–99. https://doi.org/10.1007/s10548-005-0278-6

Spencer, K. M., Dien, J., & Donchin, E. (1999). A componential analysis of the ERP elicited by novel events using a dense electrode array. *Psychophysiology*, *36*(3), 409–414. https://doi.org/10.1017/s0048577299981180

Spencer, K. M., & Polich, J. (1999). Poststimulus EEG spectral analysis and P300: attention, task and probability. *Psychophysiology.*, *36*(2), 220–232. https://doi.org/10.1111/1469-8986.3620220

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology*, *38*(4), 387–401. https://doi.org/10.1016/0013-4694(75)90263-1

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica*, *30*, 276–315. https://doi.org/10.1016/0001-6918(69)90055-9

Sukov, W., & Barth, D. S. (1998). Three-dimensional analysis of spontaneous and thalamically evoked gamma oscillations in auditory cortex. *Journal of Neurophysiology*, *79*(6), 2875–2884. https://doi.org/10.1152/jn.1998.79.6.2875

Sur, S., & Sinha, V. K. (2009). Event-related potential: An overview. *Industrial Psychiatry Journal*, *18*(1), 70–73. https://doi.org/10.4103/0972-6748.57865

Tenke, C. E., Kayser, J., Shankman, S. A., Griggs, C. B., Leite, P., Stewart, J. W., & Bruder, G. E. (2008). Hemispatial PCA dissociates temporal from parietal ERP generator patterns: CSD components in healthy adults and depressed patients during a dichotic oddball task. *International Journal of Psychophysiology*, *67*(1), 1–16. https://doi.org/10.1016/j.ijpsycho.2007.09.001

Thompson, B. (2004). *Exploratory and confirmatory factor analysis: Understanding concepts and applications*. Washington, DC: American Psychological Association.

Thurstone, L. L. (1947). *Multiple factor analysis*. Chicago: University of Chicago Press.

Van Boxtel, G. J. M. (1998). Computational and statistical methods for analyzing event-related potential data. *Behavior Research Methods, Instruments, & Computers*, *30*(1), 87–102. https://doi.org/10.3758/BF03209419

Vanderploeg, R. D., Brown, W. S., & Marsh, J. T. (1987). Judgements of emotion in words and faces: ERP correlates. *International Journal of Psychophysiology*, *5*(3), 193–205. https://doi.org/10.1016/0167-8760(87)90006-7

Verleger R. (2020). Effects of relevance and response frequency on P3b amplitudes: Review of findings and comparison of hypotheses about the process reflected by P3b. *Psychophysiology*, *57*(7), Article e13542. https://doi.org/10.1111/psyp.13542

Verleger, R., Paulick, C., Möcks, J., Smith, J. L., & Keller, K. (2013). Parafac and go/no-go: Disentangling CNV return from the P3 complex by trilinear component analysis. *International Journal of Psychophysiology*, *87*(3), 289–300. https://doi.org/10.1016/j.ijpsycho.2012.08.003

Wei, G., Rushby, J. A., & De Blasio, F. M. (2019). Neurophysiological correlates of visuospatial attention and the social dynamics of gaze processing. *Cognitive, Affective & Behavioral Neuroscience*, *19*(5), 1218–1230. https://doi.org/10.3758/s13415-019-00728-w

Wendel, K., Väisänen, O., Malmivuo, J., Gencer, N. G., Vanrumste, B., Durka, P., Magjarević, R., Supek, S., Pascu, M. L., Fontenelle, H., & Grave de Peralta Menendez, R. (2009). EEG/MEG source imaging: methods, challenges, and open issues. *Computational Intelligence and Neuroscience*, *2009*, Article 656092. https://doi.org/10.1155/2009/656092

Wessel, J. R. (2018). Prepotent motor activity and inhibitory control demands in different variants of the go/no-go paradigm. *Psychophysiology*, *55*(3), Article e12871. https://doi.org/10.1111/psyp.12871

Widmann, A., Schröger, E., & Wetzel, N. (2018). Emotion lies in the eye of the listener: Emotional arousal to novel sounds is reflected in the sympathetic contribution to the pupil dilation response and the P3. *Biological Psychology*, *133*, 10–17. https://doi.org/10.1016/j.biopsycho.2018.01.010

Winterer, G., Egan, M. F., Raedler, T., Sanchez, C., Jones, D. W., Coppola, R., & Weinberger, D. R. (2003). P300 and genetic risk for schizophrenia. *Archives of General Psychiatry*, *60*(11), 1158–1167. https://doi.org/10.1001/archpsyc.60.11.1158

Wood, C. C., & McCarthy, G. (1984). Principal component analysis of event-related potentials: Simulation studies demonstrate misallocation of variance across components. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *59*(3), 249–260. https://doi.org/10.1016/0168-5597(86)90018-3

Wood, J. M., Tataryn, D. J., & Gorsuch, R. L. (1996). Effects of under-and overextraction on principal axis factor analysis with varimax rotation. *Psychological Methods*, *1*(4), 354–365. https://doi.org/10.1037/1082-989X.1.4.354

Woodman G. F. (2010). A brief introduction to the use of event-related potentials in studies of perception and attention. *Attention, perception & psychophysics*, *72*(8), 2031–2046. https://doi.org/10.3758/APP.72.8.2031

Yang, W., Ren, Y., Yang, D. O., Yuan, X., & Wu, J. (2016). The Influence of Selective and Divided Attention on Audiovisual Integration in Children. *Perception*, *45*(5), 515–526. https://doi.org/10.1177/0301006616629025

Yao, J., & Dewald, J. P. (2005). Evaluation of different cortical source localization methods using simulated and experimental EEG data. *NeuroImage*, *25*(2), 369–382. https://doi.org/10.1016/j.neuroimage.2004.11.036

Yates, A. (1988). *Multivariate exploratory data analysis: A perspective on exploratory factor analysis*. Albany: State University of New York Press.

Chapter 2. Sequential Processing in the Classic Oddball Task: ERP Components, Probability, and Behaviour

Foreword

This chapter is based on the first accepted journal article of this thesis, corresponding to Experiment 1, which compared the sequential processing and behaviour in uncued auditory oddball and equiprobable tasks. Additional material has been added to extend the accepted article for this thesis after its publication in the journal, *Psychophysiology*. A copy of the published article is printed in Appendix C for reference.

Citation

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Author Contributions

JSF and RJB conceptualised this study. JSF performed the data collection, analyses, and interpretation of the outcomes under the supervision of RJB and GZS. The journal article was drafted and finalised by JSF following critical revisions provided by RJB and GZS. All authors approved the final article prior to submission.

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June 11, 2020	June 11, 2020	June 11, 2020

Abstract

This study compared the ERP components and behaviour associated with the auditory equiprobable and classic oddball tasks, to relate the cognitive processing stages in those paradigms, and continue the development of the Sequential Processing Schema. Target and nontarget ERP data were acquired from 66 healthy young adults (M_{age} = 20.1, *SD* = 2.4 years, 14 male) who completed both equiprobable (target p = .5) and oddball tasks (target p = .3). Separate temporal PCAs were used to decompose the ERP data in each task and condition, and the similarity of the components identified in each condition was examined between tasks. Probability effects on component amplitudes and behaviour were also analysed to identify task differences in cognitive demands. A highly similar series of components was identified in each task, closely matching the Schema: targets elicited N1-3, N1-1, PN, N2c, P3b, SW1, and SW2; whereas nontargets elicited N1-3, N1-1, PN, N2b, P3a, SW1, and SW2. N1-1 and PN amplitudes increased as stimulus probability decreased, irrespective of the condition. N2b, P3b, SW1, and SW2 amplitudes also varied between tasks, illustrating task-specific demands on those processing stages. These findings complemented the behavioural outcomes, which demonstrated greater accuracy and control in the classic oddball task. Overall, this study demonstrated comparable processing in the auditory equiprobable and classic oddball tasks, extending the generalisability of the Schema and enabling further integration of the ERP theory associated with these tasks. This study also clarifies stimulus probability effects on the Schema, providing important insight into the functionality of common ERP components.

Keywords: Behaviour, Equiprobable, ERP components, Oddball, Principal Components Analysis (PCA), Probability

1. Introduction

1.1. The classic oddball task

In the classic oddball task, participants are presented with a series of target and nontarget stimuli and are required to respond to targets and ignore nontargets. The defining feature of this task is that the global probability of target presentation is lower than for nontargets, thus increasing the deviance of target stimuli and facilitating research into cognitive processes like stimulus classification, attention, response selection, and activation (e.g., Garcia-Larrea et al., 1992). This *a priori* probability structure is at the opposite extreme from the traditional Go/NoGo task (which incorporates fewer nontargets) and is an important characteristic that distinguishes oddball tasks from similar two-choice paradigms (Donchin & Coles, 1988).

1.2. The equiprobable task

The equiprobable task is a simple choice-RT task that features an equal number of target and nontarget stimuli, balancing the global stimulus probability. This is a valuable alternative to the oddball task when researchers need to maximise data acquisition for each condition (Barry & De Blasio, 2015; Key & Yoder, 2013). Considering this use, and their similar design, equiprobable tasks are also referred to as equiprobable or 50% oddball tasks (e.g., Barry et al., 2000; Steiner et al., 2014a). However, few studies have formally compared the neuronal/cognitive and behavioural processing in these two tasks. The extent that equiprobable target and nontarget processing parallels that in the oddball task needs to be determined so that researchers can properly integrate and develop the theory and research associated with these two paradigms. This is also important to clarify given that equiprobable tasks are used in Go/NoGo contexts with different cognitive demands; hence, understanding the relationship between these tasks has critical implications for their application in two-choice research.

1.3. Linking the equiprobable and oddball tasks

In this study we focus on event-related potentials (ERPs) in equiprobable and oddball tasks, as these measures provide valuable insight into cognitive task processing at a high temporal resolution. Prior research indicates that ERPs in each of these tasks feature the common P1, N1, P2, N2, P3 and SW ERP components. However, the specificity of the mismatch negativity (MMN; Näätänen et al., 2007) and novelty P3 (nP3; Barry, Steiner, & De Blasio, 2016; Courchesne et al., 1975) to deviant (and in terms of probability, infrequent) stimuli, also suggests that there could be important cognitive differences between equiprobable and classic oddball tasks. This could reflect further sensory processing (Duncan et al., 2009; Escera et al., 1998; Näätänen et al., 2007), or perhaps strategic changes to manage conflict and facilitate goal-directed behaviour (e.g., Botvinick et al., 2001). Different cognitive demands can also be evident in behavioural performance, as illustrated by the typical speed-accuracy trade-off relative to stimulus probability; response speed usually increases with target probability, while accuracy and control decreases (e.g., Duncan-Johnson & Donchin, 1982).

Research into stimulus probability effects on ERP components in two-choice tasks offer a useful resource for examining the similarities and differences between equiprobable and oddball processing within subjects. Table 1 summarises the ERP components and probability effects in the studies comparing simple auditory equiprobable and classic oddball processing, which were identified through systematic Go/NoGo and oddball literature analyses (see Chapter 1 and Appendix B) and further review of the broader ERP and stimulus probability literature. It is important to note that the studies in Table 1 represent only those that compared simple (uncued two-stimulus) auditory equiprobable and oddball task effects on ERP components; this is not an exhaustive review of ERPs or probability across all two-choice stimulus discrimination tasks.

In the auditory modality, N. Squires et al.'s (1975) early event-related potential (ERP) research using temporal principal components analysis (PCA) illustrates similar P1, N1, P2, N2, P3, and slow wave (SW) ERP components at different levels of target probability (0.1, 0.5, 0.9) in an oddball counting task. Also, in that study, a frontocentral nontarget P3 (i.e., P3a, sometimes referred to as P250; Comerchero & Polich, 1999; Garcia-Larrea et al., 1992) was distinguished from the larger and more parietal target P3 (i.e., P3b). ERP component amplitudes also increased as stimulus probability decreased, showing that the cognitive processes underlying N1, N2, P3a, and P3b required greater neuronal activation when stimuli were rare (but note: P2 showed the opposite trend and the effects for N1 and P2 did not reach significance). Duncan-Johnson and Donchin (1977) replicated these PCA findings and found significant effects on all factors over a greater range of target probabilities, although a parietal P4 (P400) was extracted across participants instead of the early P3a, possibly reflecting the influence of a late P3 (i.e., P400) component observed in the data of two participants.

Auditory probability research using traditional ERP measures (e.g., baseline-to-peak) also indicate a similar ERP component series across these two classic tasks, both when targets are counted or when a motor response is required (Banquet et al., 1981; Brigham et al., 1995; Polich et al., 1994; Polich & Margala, 1997; Spencer & Polich, 1999). The comparability of equiprobable and oddball ERP components and processing may also be reinforced (but also largely assumed) in studies exploring probability effects on one or two components, rather than the more complete task-processing series (Dalbokova et al., 1990; Eliades et al., 2014; Hull & Harsh, 2001; Verleger & Berg, 1991). These studies all confirm the negative correlation between P3 amplitudes and stimulus probability, however, the effects on N1, P2, and N2 are somewhat less reliable; different effects may also exist across target and nontarget conditions (see Spencer & Polich, 1999). Similar findings are also evident in studies that examined equiprobable and oddball probabilities using different stimulus modalities or other complex task manipulations (e.g., Bruin & Wijers, 2002; Duncan-Johnson & Donchin, 1982; Key & Yoder, 2013; Nieuwenhuis et al., 2003; Polich & Margala, 1997; K. Squires et al., 1977; Verleger & Berg, 1991); however, here we focus on simple auditory tasks.

Table 1

Previous Studies Testing ERP Differences Between Simple Auditory Equiprobable and Oddball Tasks

Study Citation	*P*(target)	*N*	Sites	ERP Method	Task	Identified ERP Components
N. Squires et al. (1975)	.1, .5, .9	6	3	Traditional and tPCA	C	**N1**, **P2**, **N2**$^{\downarrow}$, **P3a**$^{\downarrow}$, **P3b**$^{\downarrow}$, **SW**$^{\downarrow}$
Duncan-Johnson & Donchin (1977)	.1, .2, .3, .4, .5, .6, .7, .8, .9	10	5	Traditional and tPCA	C	**N1**$^{\downarrow}$, **P2**$^{\uparrow}$, **P3**$^{\downarrow}$, **P4**$^{\downarrow}$, **SW**$^{\downarrow}$
Banquet et al. (1981)	.2, .5, .8	6	3	Traditional	M	N1, P2, **N2**$^{\downarrow}$, **P3**$^{\downarrow}$, **P4**$^{\downarrow}$
Dalbokova et al. (1990)	.1, .3, .5	15	3	Traditional	C	**P3**$^{\downarrow}$
Polich et al. (1994)	.2, .5, .8	16	3	Traditional	M	**N1**$^{\downarrow}$, **P2**, **N2**, **P3**$^{\downarrow}$
Brigham et al. (1995)	.1, .3, .5	54	5	Traditional	C	P1, N1, P2, N2, P3, SW (Nc)
Polich & Margala (1997)	.1, .3, .5, .7, .9	16	3	Traditional	M	**N1**‡, **P2**‡, **N2**‡, **P3**$^{\downarrow}$
Spencer & Polich (1999)	.2, .5, .8	16	1	Traditional	C	GO: **N1**$^{\downarrow}$, **P2**$^{\uparrow}$, **N2**$^{\downarrow}$, **P3**$^{\downarrow}$ NG: **N1**$^{\uparrow}$, **P2**$^{\downarrow}$, **N2**$^{\downarrow}$, **P3**$^{\downarrow}$
Hull & Harsh (2001)	.2, .5, .8	10	3	Traditional	M	**P3**$^{\downarrow}$
Eliades et al. (2014)	.2, .5, .8	5	iEEG	Traditional	P	**N1**, **P2**

N.B. 'Sites' refers to the number of EEG scalp sites used. C = Counting Task. M = Motor Task. GO = Go, target condition. NG = NoGo, nontarget condition. The *amplitudes* of ERP components in bold text were analysed. Arrows describe significant effects of increasing stimulus probability (i.e., ↑ = increased amplitudes; ↓ = decreased amplitudes; no arrow = no significant effect). ‡ = significant probability effect reported without a clear direction. iEEG = intra-cranial EEG. tPCA = temporal PCA.

Although the number and identification of P3 factors varies across the studies in Table 1, the general indication is that the same ERP components can be identified between both the simple equiprobable and oddball tasks. This suggests that the auditory equiprobable and classic oddball processing series (and/or requirements) are comparable or equivalent, but that discrete variations in target/nontarget cognitive demands exist between the tasks, as indicated by the task differences (i.e., probability effects) in ERP amplitudes. However, the studies in Table 1 utilise an extremely low number of scalp sites (≤ 5 derivations). The traditional and PCA methods used are also biased to identify a similar series of ERP components. For example, submitting equiprobable and oddball ERPs to one *combined* PCA will forcibly extract a fixed set of factors across conditions (Barry, De Blasio, Fogarty, & Karamacoska, 2016). A similar issue arises when applying traditional measures to operationalise data in each condition. Thus, with these methods and such low spatial

resolution, the previous studies comparing equiprobable and oddball processing were likely insensitive to important task differences in the ERP component series.

1.4. The Sequential Processing Schema

In their early PCA research, Barry and De Blasio (2013) proposed a sequential processing schema that used ERP components to delineate the neurocognitive processes in an auditory equiprobable task. Temporal PCA was used to extract target and nontarget components, providing an effective data-driven method to chart important electrocortical events in each condition; including their latency, order, and duration (represented by factor loadings; Dien & Frishkoff, 2005). Previous ERP literature guides the identification and interpretation of extracted components; hence, the Schema is not a theory itself, but an empirical model, which can be used to synthesise and test theories regarding a range of ERP components. This then provides a simple and effective framework to measure, illustrate, and interpret experimental effects on several cognitive processes in the equiprobable paradigm.

Components in the Schema are considered to mark separate functional events, which are often considered to reflect 'stages' of processing; however, this is merely a simplification. The Schema does not assume or strictly adhere to 'stage-based' views of cognition (e.g., Sternberg, 1969), as components within the Schema can overlap temporally. Indeed, the component-processes often begin before the completion or culmination (i.e., peak) of previous components, which can support continuous-flow perspectives of cognition (see Coles et al., 1985). Despite that, these conceptual deliberations remain flexible as this working model continues to develop through progressive and iterative ERP research.

Following conceptual and methodological improvements, such as the now standard application of *separate* PCAs within conditions (*cf.* combined PCA; Barry, De Blasio, Fogarty, & Karamacoska, 2016), Barry and colleagues have produced updated versions of the Schema for children (Barry et al., 2018), and for young adults (Fogarty et al., 2018). The young adult Schema in Fogarty et al. (2018) starts with the auditory P1 and N1-3 components, representing early sensory and attentional mechanisms involved in stimulus detection (Figure 1); however, these components are not always identified using PCA, given they account for such a small proportion of ERP variance (typically < 1%; Barry & De Blasio, 2013). N1-3 is followed by N1-1 and processing negativity (PN), signifying the onset of stimulus categorisation (for a review of these N1 subcomponents, see Näätänen & Picton, 1987). Successful target categorisation is marked by P2, followed by N2c, P3b, and a classic SW, reflecting further target-specific response processing. Alternatively, nontargets elicit N2b, P3a and a late slow-wave positivity (LP), marking the categorisation of nontargets and the termination of active response processing.

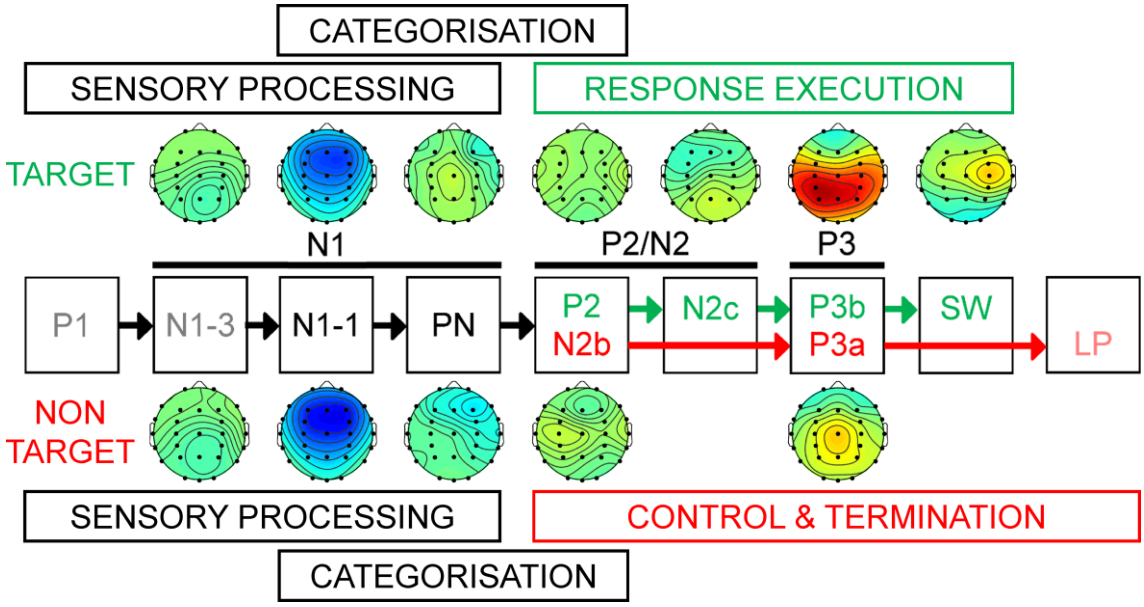


Figure 1. The updated Sequential Processing Schema in Fogarty et al. (2018). The corresponding component headmaps were extracted from the ERP data in that study. Note: P1, N1-3, and LP labels are faded as their mapping is more variable.

The Sequential Processing Schema has proven to be a reliable research tool in studies of a range of target/nontarget processes over the lifespan (Barry, De Blasio, & Borchard, 2014; Barry, De Blasio, & Cave, 2016), with pharmacological manipulation (Barry, De Blasio, & Cave, 2014), variable stimulus onset asynchronies (SOAs; Borchard et al., 2015), brain dynamics (Barry, De Blasio, De Pascalis, & Karamacoska, 2014; Barry et al., 2018; Karamacoska et al., 2017, 2018), and in relation to behaviour (Barry & De Blasio, 2015; Barry et al., 2018; Fogarty et al., 2018). In the same way, the comprehensive data-driven approach used to quantify and test the broad ERP processing series in the Schema would be a valuable framework to compare target and nontarget processing in the auditory equiprobable and classic oddball tasks. Linking the components in the equiprobable and oddball tasks would also provide valuable insight into the generalisability of the Schema as a holistic ERP data-driven model of simple auditory Go/NoGo and active oddball task processing.

1.5. The present study

Previous studies have examined ERP component differences between simple auditory equiprobable and oddball task processing, however, those studies were designed to examine probability effects on certain components rather than characterise and compare the cognitive processing requirements in each task. There is a need for data-driven ERP studies with increased spatial resolution and sample sizes to delineate the processing series within each task condition and test the similarities and differences between these popular two-choice tasks within subjects; this could have valuable implications for equiprobable task utility and the fundamental ERP component structure and functionality within each paradigm.

Accordingly, the aim of the present study was to relate target and nontarget processing in the simple auditory equiprobable and classic oddball tasks, by comparing the range of ERP components and behaviour elicited in a large sample of healthy young adults using separate temporal PCAs; unlike the previous studies, this will allow the unique task and condition-specific variance to define the extracted ERP factor series. This investigation was also designed to determine if the young adult Sequential Processing Schema applies to the classic oddball task, to continue the development of that model. The Schema has not been examined in a classic oddball framework, although many of the ERP components forming the model are relevant to oddball paradigms. As such, a similar range of components was expected to be identified in each task, closely replicating the Sequential Processing Schema.

ERP component amplitudes were likely to vary between tasks, reflecting the different cognitive demands. Following N. Squires et al. (1975) and Duncan-Johnson and Donchin (1977), the target and nontarget N1-1, N2, and P3 component amplitudes were expected to vary as a negative function of stimulus probability, while P2 was predicted to show the opposite pattern. Task-specific components (e.g., MMN, nP3) may also be identified, marking additional processes associated with rare targets. Behavioural performance outcomes were also anticipated to follow the typical speed-accuracy trade-off, relative to target probability (e.g., Duncan-Johnson & Donchin, 1982).

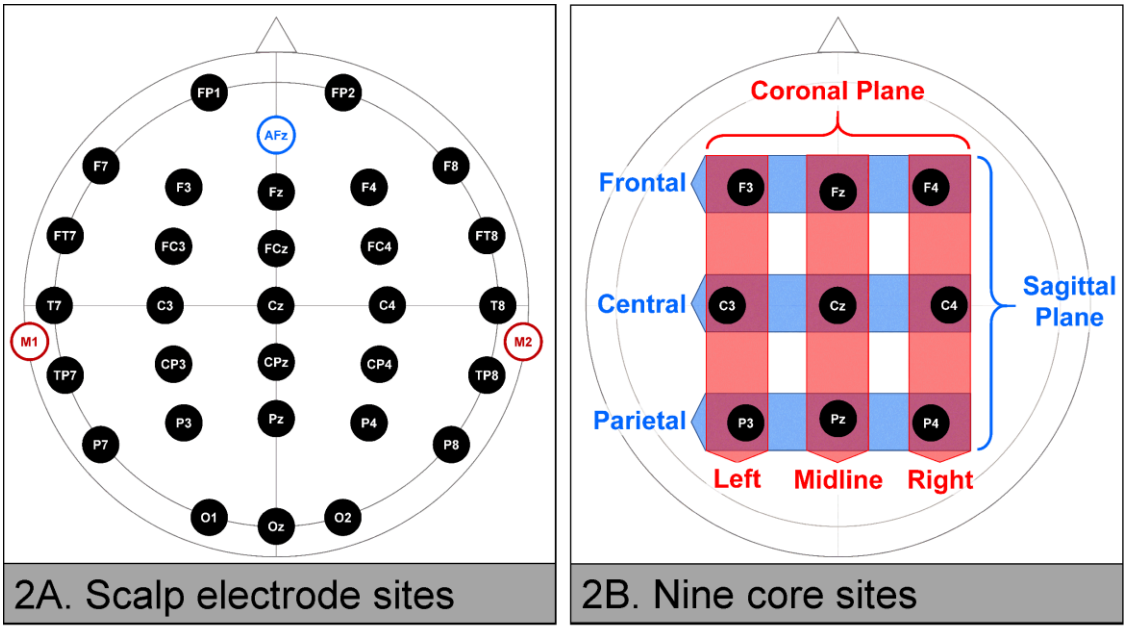
2. Method

2.1. Participant demographics and screening

Sixty-six young adults volunteered to participate in this research through the University of Wollongong, School of Psychology Research Participation Scheme to gain additional course credit (M_{age} = 20.1, *SD* = 2.4 years; 14 males). All participants were right-handed, gave written informed consent, and self-reported no ongoing mental health issues, neurological disorders, or previous head injuries causing unconsciousness. Each participant had also abstained from caffeine/tobacco (> 4 h) and psychoactive substances (> 12 h) before testing. This procedure was conducted with the approval of the University of Wollongong and Illawarra Shoalhaven Local Health District Human Research Ethics Committee.

2.2. Physiological recording

Continuous electrophysiological data from DC to 30 Hz (sampled at 1000 Hz) were recorded using a Neuroscan Synamps2 Amplifier. EEG was recorded with electrodes at the right mastoid (M2) and 30 derivations across the scalp, all referenced to the left mastoid (M1) and grounded at AFz (Figure 2A). EOG data were also recorded at four sites: two adjacent to the outer canthi, and two above and below the left eye. All EEG and EOG electrodes were sintered Ag/AgCl, with impedances below 5 kΩ.



Topographical Analyses

Component topographies were defined using repeated measures MANOVAs, following Barry, De Blasio, Fogarty et al. (2016). The repeated measures included component amplitudes in the **sagittal plane** (frontal [F3, Fz, F4]; central [C3, Cz, C4]; parietal [P3, Pz, P4]), and **coronal plane** (left [F3, C3, P3]; midline [Fz, Cz, Pz]; right [F4, C4, P4]). For PN the hemispheric sites (e.g., F3/4) were substituted by F7/8, T7/8, and P7/8, to account for its temporal distribution.

Planned sagittal contrasts compared the average of frontal (F) and parietal (P) sites, and the frontoparietal average (F/P) against central (C) sites; likewise, planned coronal contrasts examined left (L) and right (R) amplitudes, and compared the averaged hemispheres (L/R) with the midline sites (M).

Figure 2. The EEG electrode montage utilised in this study (2A) and the nine core sites (2B) used to define component topographies in the topographical analyses (lower panel).

2.3. Task and procedure

The tasks used in this study were projected onto a blank wall, in a dark sound-attenuated room, ~3 m in front of participants. Participants were seated to complete a short EOG calibration task (see Croft & Barry, 2000), before receiving equipment and instructions for the auditory equiprobable and classic oddball tasks. Each task incorporated two blocks of 150 uncued tones (1000 or 1500 Hz) presented in random order through circumaural headphones at 60 dB SPL (calibrated at the headphone using an artificial ear; Brüel & Kjær, model 4152). Tones lasted 80 ms (including 15 ms rise/fall times) and the SOA was fixed at 1250 ms, to be consistent with our prior research (Fogarty et al., 2018). Target tone frequency was counterbalanced between blocks, and task and block order alternated across subjects to minimise order effects. The global *a priori* target probability was the only difference between the two experimental tasks: equiprobable *p*(target) = .5 and classic oddball *p*(target) = .3. This oddball probability was set to establish a significant shift in target probability that is similar to other oddball tasks, while maintaining a reasonable target: nontarget ratio in each condition.

Participants were instructed to respond to target tones as quickly and as accurately as possible, and to ignore the alternate (nontarget) tone. Participants were also asked to respond with a right-handed button-press on a Logitech® Precision Gamepad Controller and fixate on a white cross displayed in front of them during each block. Before each block, participants received an example of their target tone and a short ten trial practice. Practice trials were randomly shuffled and shared the same target probability as the ensuing block.

2.4. Measure quantification

2.4.1. Behavioural performance

Individual behavioural outcomes were quantified separately for each task: Reaction times (RTs) within the SOA period were recorded in ms, with extreme RTs classified as Fast (RTs < M_{RT} − 2 *SD*) or Slow RT errors (RTs > M_{RT} + 2 *SD*). Target and nontarget accuracy were also computed as the rate of omission and commission errors, respectively. After accuracy and extreme RTs were recorded, trials including errors or electrical artefacts (see Method 2.4.2) were removed so that a final measure of the intrasubject mean RT and standard deviation of RT (ISD) could be calculated for analysis.

2.4.2. ERPs

EEG data were EOG corrected (Croft & Barry, 2000), re-referenced to linked mastoids, and lowpass filtered to 25 Hz (FIR, 24 dB/Octave, zero phase shift) in Neuroscan (Compumedics, v. 4.5). The filtered data were then epoched around stimulus onset (−100 to +750 ms) and baselined using the average amplitude over the prestimulus period. Epochs including behavioural errors or electrical data exceeding ± 100 μV at any site were rejected. The remaining trials were then averaged to generate mean target and nontarget ERPs for each participant in each task.

The target and nontarget ERP data from each task were subjected to four separate temporal PCAs in Matlab (The Mathworks, v. 8.0, R2012b), using the covariance matrix with Kaiser normalisation, and unrestricted Varimax rotation (Kayser & Tenke, 2003). These were conducted using Matlab functions provided by Kayser and Tenke (2003; http://bit.ly/2oX0etA); although those functions were modified to prevent the removal of the grand mean ERP, in line with Dien (2010) and Barry, De Blasio, Fogarty, and Karamacoska (2016). Each PCA included 1980 cases (66 participants × 30 sites) and 850 variables (timepoints). The variance, topography, and latency of the extracted factors were used to identify as many ERP components as possible; this process was guided by prior ERP research and began with the factors accounting for the most variance. Unless they were readily identified from the PCA output, factors explaining < 1.5 % were not considered further. The final components within each condition were then summed to produce virtual (reconstituted) target and nontarget ERPs for each task.

2.5. Statistical analysis

Paired sample *t*-tests (N = 66, df = 65) were used to compare the percentage of accepted trials and the behavioural outcomes between tasks. Pearson's correlations (r) were calculated

between the raw and reconstituted ERP data at three midline sites (Fz, Cz, Pz), to evaluate the virtual ERPs' goodness-of-fit, within each task and condition. Following Barry, De Blasio, Fogarty, and Karamacoska (2016), matching components identified in the separate tasks were compared using Tucker's (1951) congruence coefficient (r_c), and topographic correlations. The congruence coefficient is calculated using the unscaled factor loadings of two components and provides an indication of component similarity over time; two components were considered highly similar if $.85 \leq r_c \leq .94$, and temporally equivalent if $r_c \geq .95$ (Lorenzo-Seva & ten Berge, 2006). The topographic correlations were calculated between the component amplitudes over the 30 scalp sites.

To define the topography of each component, separate univariate repeated measures ANOVAs (using SPSS MANOVA) were applied to their peak amplitude data from nine cores sites (Figure 2B). Alpha adjustments were not necessary for these topographical analyses as the number of planned contrasts was lower than the degrees of freedom for effect (Tabachnick & Fidell, 2013). Greenhouse-Geisser type corrections were also unnecessary as single degree of freedom contrasts are not affected by violations of sphericity (O'Brien & Kaiser, 1985). Each *F* test reported has (1, 65) degrees of freedom.

In each task, mean intrasubject component amplitudes were calculated over the electrodes defining the dominant topographical features of each component; electrodes were carefully selected using the contours on the component headmaps, extending from the core topographic outcomes. Component amplitudes were then analysed between tasks using paired sample *t*-tests ($N = 66$, $df = 65$). Each *t*-test was two-tailed unless otherwise specified. An $\alpha < .05$ was needed for the statistical significance of each test presented in this study, although those nearing significance ($.05 < p < .10$) are also reported, to guide future research.

3. Results

3.1. Trial and behavioural outcomes

The percentage of accepted target trials in the classic oddball ($M = 93.2$ %, $SD = 4.2$) and equiprobable ($M = 92.6$ %, $SD = 4.6$) tasks did not differ. However, a larger percentage of nontarget trials were accepted in the oddball task ($M = 97.4$ %, $SD = 3.3$), compared to the equiprobable task ($M = 95.4$ %, $SD = 3.9$); $t(65) = -4.62$, $p < .001$. The grand mean (GM) task performance outcomes are summarised in Table 2. Commission error rates were significantly lower in the oddball task, $t(65) = 7.42$, $p < .001$. The oddball task was also linked to smaller ISDs, $t(65) = 3.79$, $p < .001$. Mean RTs also tended to be slower in the oddball than the equiprobable task, $t(65) = -1.32$, $p = .096$.

Table 2

Grand Mean (and SD) for the Behavioural Outcomes by Task

	Error Rates (%)				Target Reaction Time (ms)	
	Commissions***	Omissions	Fast RT	Slow RT	Mean	ISD***
E	2.7 (2.4)	1.5 (2.4)	0.2 (0.5)	4.1 (1.2)	374.8 (51.3)	77.9 (24.3)
O	0.8 (1.0)	1.0 (2.6)	0.3 (0.5)	4.0 (1.4)	380.4 (52.7)	69.3 (21.8)

N.B. E = equiprobable; O = oddball; ISD = intra-individual standard deviation; *** is significant at $p < .001$.

3.2. Target-specific outcomes

3.2.1. Grand mean and reconstituted target ERPs

Figure 3 compares the raw (left) GM target ERPs between the equiprobable and oddball tasks at Fz, Cz and Pz. These raw ERPs are highly comparable, with the major target components evident in the midline data, including the auditory P1, N1, P2, N2, P3 and a broad SW.

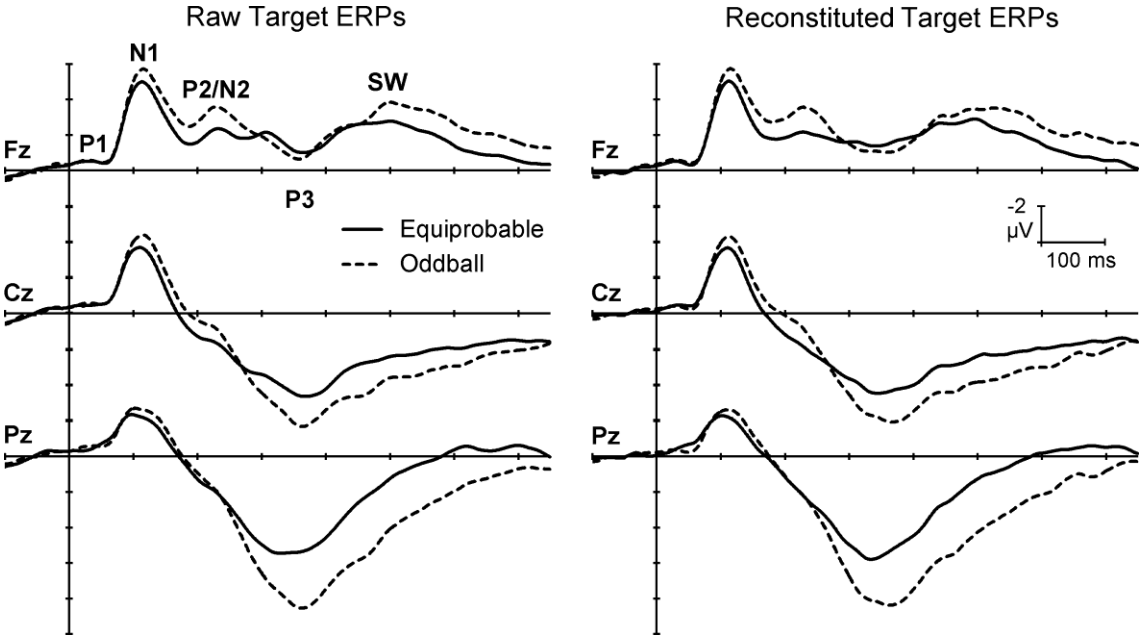


Figure 3. Raw (left) and reconstituted (right) GM target ERPs related to the equiprobable and classic oddball tasks. Major Go ERP components are marked on the raw target ERP at Fz.

3.2.2. Target PCA findings and congruence

Figure 4 displays the scaled factor loadings, headmaps and factor information associated with the target components extracted in each task. Eight components were identified in relation to equiprobable targets, including N1-3, N1-1, PN, P2, N2c, P3b, and two SW components (target SW1 and SW2). A similar series of components was linked to oddball targets, excluding P2. These components explained a total of 94.4 % and 93.0 % of the variance in the equiprobable and oddball tasks, respectively.

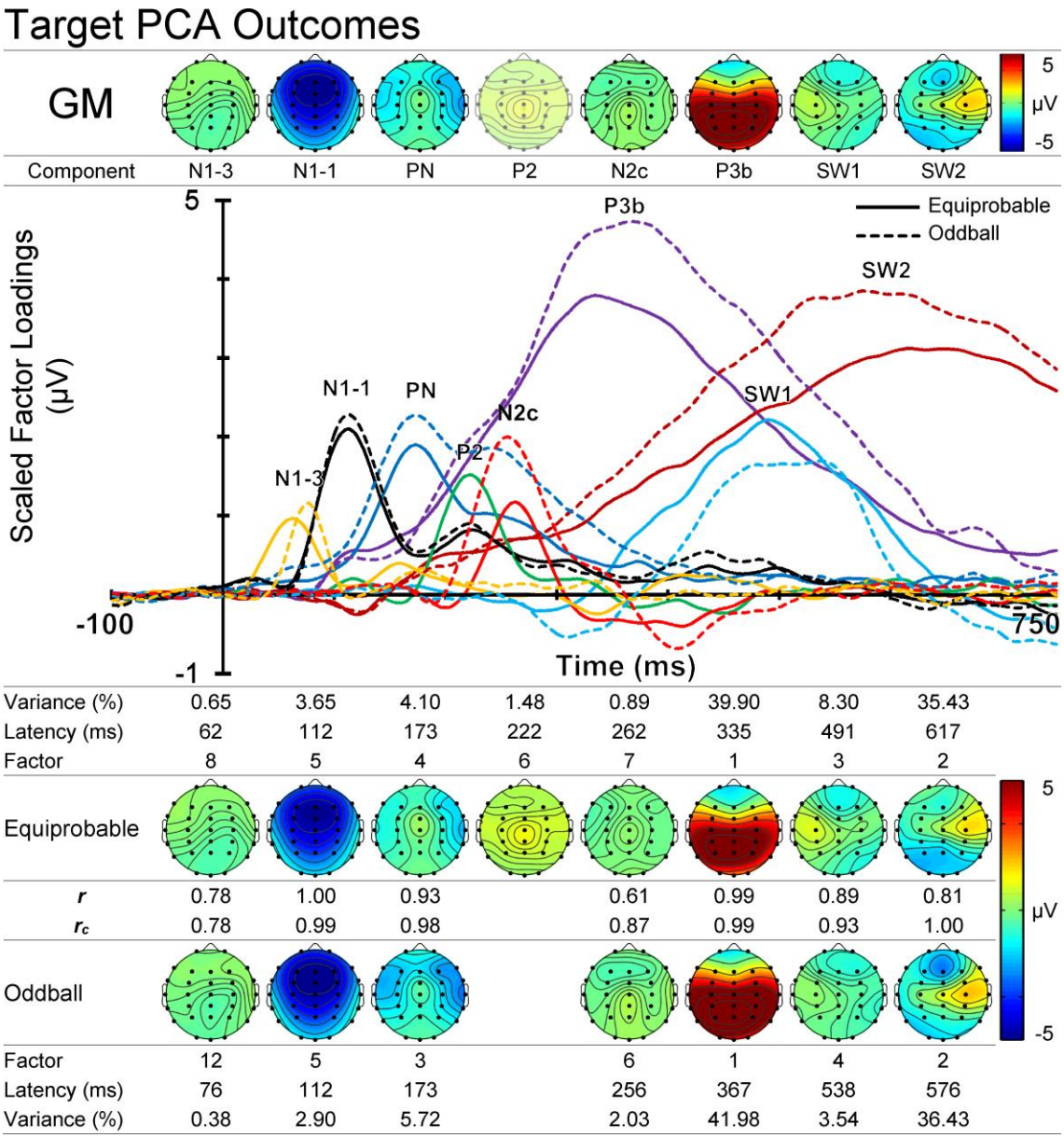


Figure 4. GM target headmaps (top), and task-specific scaled factor loadings (middle) and target components (bottom). Topographic correlations (r) and congruence coefficients (r_c) are displayed between the paired components. GM P2 is faded as it was unique to one task.

The indicators of congruence and topographic similarity of paired target components are presented between the corresponding headmaps in Figure 4. The paired components were highly similar (N2c and SW1) or equivalent over time (N1-1, PN, P3b, SW2), except for N1-3 (r_c = .78). Their topographies were also highly comparable, except for N2c, though it was still fairly comparable (r[28] = .61, p < .001). The raw and reconstituted ERP data (in Figure 3) were also highly correlated at Fz, Cz and Pz in each task (r[848] ≥ .98, p < .001), indicating a good fit between the raw and reconstituted data.

3.2.3. Target component topographies

The GM target headmaps are displayed in Figure 4, while the significant and approaching significant topographical statistics for the GM target components are reported in Table 3. These outcomes are also summarised in text, including the topographical effects for the initial components, to aid the reader's interpretation of these results.

Table 3

GM Target Topographies Across Tasks

Component	Effect	*F*	*p*	η_p^2
N1-3	F < P	10.70	.002	.14
	L < R	3.82	.055	.06
	M > L/R	10.79	.002	.14
	C > F/P × L < R	13.21	.001	.17
N1-1	F > P	96.06	< .001	.60
	C > F/P	27.09	< .001	.29
	M > L/R	168.21	< .001	.72
PN	F > P	8.50	.005	.12
	C > F/P	8.82	.004	.12
	L < R	10.52	.002	.14
	M < L/R	29.96	< .001	.32
	F > P × L < R	3.03	.086	.04
	F > P × M < L/R	3.02	.087	.04
	C > F/P × L < R	18.35	< .001	.22
	C > F/P × M < L/R	96.62	< .001	.60
P2	C > F/P	19.70	< .001	.23
	M > L/R	4.43	.039	.06
	C > F/P × M > L/R	221.84	< .001	.25
N2c	F > P	6.26	.015	.09
	C < F/P	5.82	.019	.08
	M < L/R	10.73	.002	.14
	C > F/P × M < L/R	22.87	< .001	.26
P3b	F < P	235.33	< .001	.78
	C > F/P	37.46	< .001	.37
	F < P × L > R	30.83	< .001	.32
	F < P × M > L/R	99.70	< .001	.60
SW1	C < F/P	46.40	< .001	.42
	L < R	42.59	< .001	.42
	M > L/R	3.02	.087	.04
	F > P × L > R	4.34	.041	.06
	F > P × M > L/R	7.71	.007	.11
	C < F/P × L < R	4.96	.029	.07
SW2	C < F/P	65.28	< .001	.50
	L > R	29.26	< .001	.31
	M > L/R	5.36	.024	.08
	F > P × M > L/R	7.89	.007	.11
	C < F/P × L < R	17.42	< .001	.21
	C < F/P × M < L/R	3.32	.073	.05

N.B. Effects approaching significance are in grey. F = frontal; C = central; P = parietal; F/P = frontoparietal mean; L = left hemisphere; M = midline; R = right hemisphere; L/R = hemispheric mean.

The GM target N1-3 was a parietal negativity (F < P) that was stronger in the midline (M > L/R) and centrally in the right hemisphere (C > F/P × L < R). GM target N1-1 was a large frontocentral negativity (F > P and C > F/P) that was dominant in the midline (M > L/R). Across tasks, target PN was a frontocentral negativity that was dominant in the hemispheres, particularly on the right, at central sites; these effects interacted, and temporal amplitudes were greatest centrally.

The equiprobable P2 was a small positivity that was maximal at the vertex (i.e., central-midline sites). GM N2c was strongly frontal, and dominant in the hemispheres, particularly at central sites. Over tasks, GM P3b was a large centroparietal positivity with greater parietal activity in the midline and left hemisphere. Across tasks, target SW1 was a frontoparietal negativity that was dominant in the midline and in the right hemisphere, particularly at parietal sites. GM target SW2 was also a frontoparietal negativity, but was dominant on the left and in the midline, especially frontally; central SW2 amplitudes were also largely reduced on the right.

3.2.4. Target amplitudes and task effects

The *t*-test results comparing mean target component amplitudes between tasks are summarised in Table 4. These analyses did not include P2 as it was unique to the equiprobable task. Also, given that SW components are thought to comprise positive and negative subcomponents (Fitzgerald & Picton, 1981) the positive and negative features of SW1 and SW2 were quantified and analysed separately (as in Karamacoska et al., 2018). However, it was deemed inappropriate to compare the target SW2 negativity (i.e., SW2−) between tasks, considering it was frontal in the classic oddball task, but parietal in the equiprobable (Figure 4). Target N1-3 amplitudes were averaged over P3, Pz, CPz, CP4 and C4; N1-1 was averaged across Fz, FC3, FCz and FC4; PN over FT7, T7, FT8 and T8; N2c across FC3, F3, Fz, F4 and FC4; while P3b amplitudes were computed over P3, Pz, CP3 and CPz. Target SW1− was averaged over Fz, F4, CP4, and P4; SW1+ across FC3, CP3, C3, Cz and C4; and SW2+ over Cz, C4 and T8. Target N1-1, PN and P3b amplitudes were significantly larger in the classic oddball task, whereas SW1+ was smaller, relative to that in the equiprobable task.

Table 4

Task Differences in Target Component Amplitudes

Target Component	Mean Amplitudes (and *SD*)		*t*	*p*	Cohen's *d*
	Equiprobable	Oddball			
N1-3	−0.43 (1.1)	−0.38 (1.1)	−.30	.764	.04
N1-1	−4.63 (2.1)	−5.03 (2.1)	2.07	.021 †	−.19
PN	−1.56 (1.4)	−2.34 (1.7)	6.56	< .001 †	−.50
N2c	−0.25 (1.4)	−0.46 (2.4)	.84	.204 †	−.11
P3b	6.50 (3.5)	8.56 (4.7)	−4.59	< .001 †	.50
SW1+	0.42 (2.2)	0.14 (1.8)	2.32	.023	−.14
SW1−	−0.80 (2.2)	−0.76 (1.6)	−.15	.881	.02
SW2+	1.07 (2.6)	1.41 (3.4)	−1.02	.310	.11

N.B. One-tailed *p* value†. Shaded components did not differ significantly between tasks.

3.3. Nontarget-specific outcomes

3.3.1. Grand mean and reconstituted nontarget ERPs

The raw GM nontarget ERPs in each task were markedly similar at Fz, Cz and Pz, showing an early P1, N1, N2, P3 and SW (Figure 5). Slight amplitude differences were evident between tasks, particularly later in the epoch at frontal and central sites.

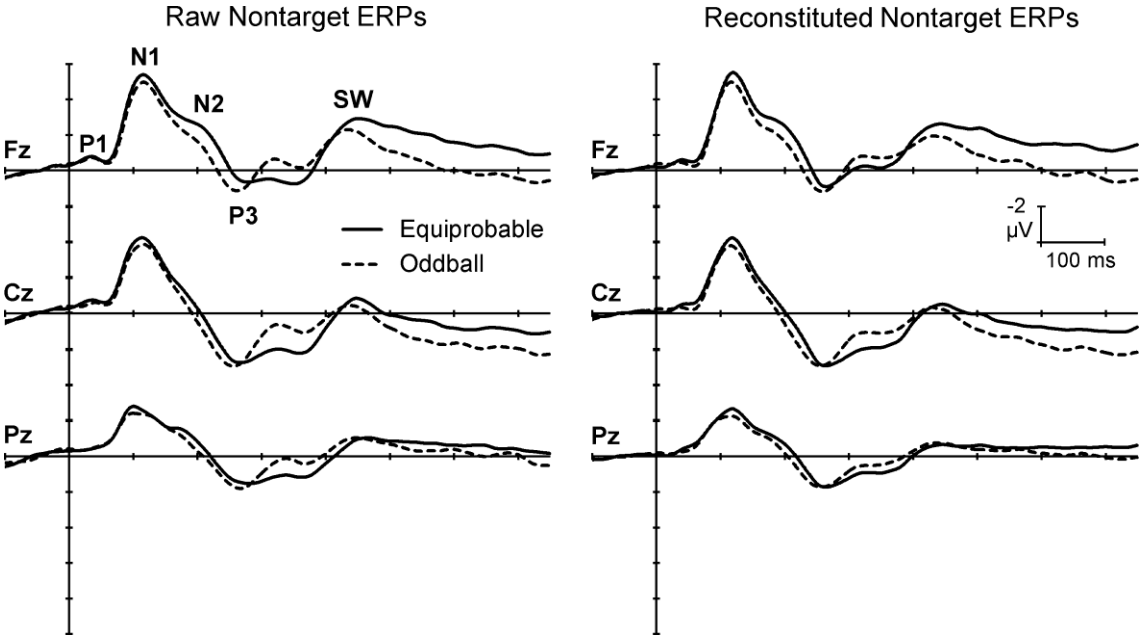


Figure 5. Raw (left) and reconstituted (right) GM nontarget ERPs associated with each task. Major nontarget ERP components are labelled on the raw ERP at Fz.

3.3.2. Nontarget PCA findings and congruence

Figure 6 displays the nontarget PCA output and the similarity of the nontarget ERP components paired between tasks. Seven components were identified in each task, including N1-3, N1-1, PN, N2b, P3a, and a nontarget SW1 and SW2. These components accounted for a total of 88.8 % and 89.7 % of the nontarget ERP variance in the equiprobable and oddball tasks,

respectively. These components had comparable topographies across tasks ($r[28] \geq .61$, $p < .001$), and were highly similar (N1-3, PN) or equivalent over time (N1-1, P3a, SW1, SW2); excluding N2b (r_c = .73). Also, although PN's topography was highly similar across tasks, frontal PN amplitudes were notably larger in the oddball task (Figure 6). The raw and reconstituted ERPs in Figure 5 were also highly correlated ($r[848] \geq .97$, $p < .001$), indicating a good fit between the raw and reconstituted nontarget ERP data.

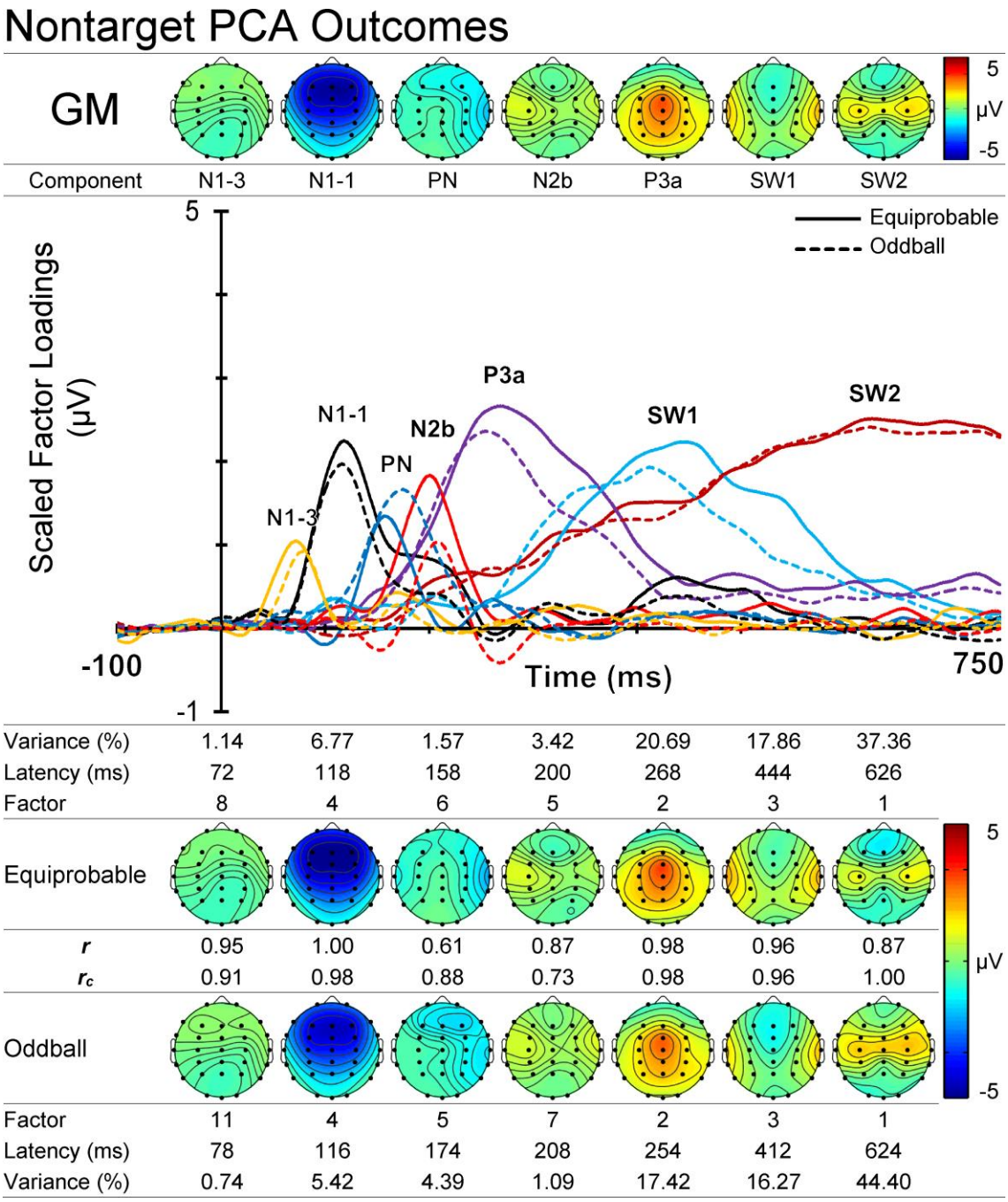


Figure 6. GM nontarget headmaps (top), task-specific scaled factor loadings (middle) and the headmaps, topographic correlations (r), and congruence coefficients (r_c) for the corresponding nontarget components, across tasks (bottom).

3.3.3. Nontarget component topographies

The defining topographies of the GM nontarget components are detailed statistically in Table 5 and are summarised in text, along with the computation of the nontarget component amplitudes. The corresponding GM headmaps are displayed in Figure 6.

Table 5
GM Nontarget Topographies Across Tasks

Component	Effect	*F*	*p*	η_p^2
N1-3	F < P	45.45	< .001	.41
	M > L/R	7.09	.010	.10
N1-1	F > P	183.85	< .001	.74
	C > F/P	40.27	< .001	.38
	M > L/R	72.34	< .001	.53
	F > P × M < L/R	4.53	.037	.06
	C > F/P × L > R	2.92	.092	.04
PN	F > P	3.33	.072	.05
	C > F/P	9.53	.003	.13
	L < R	55.64	< .001	.46
	M < L/R	7.23	.009	.10
	F < P × M < L/R	17.06	< .001	.21
	C > F/P × L < R	14.92	< .001	.21
	C > F/P × M < L/R	36.77	< .001	.36
N2b	C < F/P	100.24	< .001	.61
	L < R	19.85	< .001	.23
	M > L/R	15.28	< .001	.19
	F > P × L > R	3.90	.053	.06
	F > P × M > L/R	14.29	< .001	.18
	C > F/P × L < R	12.34	.001	.16
P3a	F < P	9.27	.003	.12
	C > F/P	52.56	< .001	.45
	L > R	4.84	.031	.07
	M > L/R	95.53	< .001	.60
	F > P × L > R	12.33	.001	.16
	C > F/P × M > L/R	31.50	< .001	.33
SW1	F > P	19.27	< .001	.23
	C < F/P	8.74	.004	.12
	M > L/R	53.33	< .001	.45
	C > F/P × M > L/R	45.57	< .001	.41
SW2	C > F/P	106.17	< .001	.62
	M < L/R	12.88	.001	.16

N.B. Effects approaching significance are in grey. F = frontal; C = central; P = parietal; F/P = frontoparietal mean; L = left hemisphere; M = midline; R = right hemisphere; L/R = hemispheric mean.

GM nontarget N1-3 was a small parietal negativity that was larger in the midline. Across tasks, nontarget N1-1 was a frontocentral negativity that was enhanced in the midline, particularly at parietal sites. The GM nontarget PN was central with maximal amplitudes at temporal sites, which were enhanced parietally; PN was also larger on the right, particularly at central sites.

Across tasks, N2b was a small frontoparietal negativity that was dominant at the midline and on the right; midline N2b amplitudes were larger frontally and in the right hemisphere at central sites. GM P3a was a centroparietal positivity that was greater in the midline and on the

left, especially at frontal sites; P3a amplitudes were maximal at the vertex. Over tasks, nontarget SW1 was a strong frontal negativity that was dominant in the midline, especially at central sites. GM nontarget SW2 was a central positivity that was maximal in the hemispheres.

3.3.4. Task effects on nontarget component amplitudes

The *t*-test outcomes comparing nontarget component amplitudes between tasks are presented in Table 6. Consistent with the nontarget topographical analyses and component headmaps, mean nontarget N1-3 amplitudes were calculated across P3, Pz, P4 and CPz; nontarget N1-1 was averaged over Fz, FCz, FC3 and FC4; PN across T7 and T8; N2b over Fz and F4; and P3a across FCz and Cz. Nontarget SW1− was averaged across F3, Fz, F4, and FCz; mean SW1+ was computed over T7 and T8; nontarget SW2− was averaged across Fz and Pz; whereas mean SW2+ was computed over C3, Cz and C4. The nontarget N1-1, PN, N2b, SW1+, and SW2− were significantly smaller in the classic oddball task. Larger nontarget SW1− and SW2+ amplitudes were found in the oddball task, compared to their equiprobable counterparts.

Table 6

Task Differences in Nontarget Component Amplitudes

Nontarget Component	Mean Amplitudes (and *SD*)		*t*	*p*	Cohen's *d*
	Equiprobable	Oddball			
N1-3	−0.65 (1.9)	−0.58 (0.9)	−.45	.653	.05
N1-1	−4.88 (2.2)	−4.12 (1.9)	−4.04	< .001 †	.37
PN	−1.77 (1.0)	−1.05 (1.0)	−6.07	< .001 †	.72
N2b	−0.52 (2.5)	−0.01 (1.2)	−1.96	.028 †	.26
P3a	2.90 (3.9)	2.64 (3.3)	.82	.208 †	−.07
SW1+	2.08 (1.3)	1.76(1.1)	2.09	.040	−.27
SW1−	−0.27 (2.3)	−1.01(2.0)	3.01	.004	−.34
SW2+	0.94 (2.2)	1.70(2.1)	−3.86	< .001	.35
SW2−	−1.10 (2.3)	−0.15(2.2)	−4.21	< .001	.42

N.B. One-tailed *p* value †. Shaded components did not differ significantly between tasks.

4. Discussion

4.1. Study overview

The aim of this study was to link the cognitive processing in the auditory equiprobable and classic oddball tasks, in relation to the young adult Sequential Processing Schema (Barry & De Blasio, 2013; Fogarty et al., 2018). To do so, we compared the series of ERP components and behaviour elicited in healthy young adults completing those two-choice tasks. As predicted, a highly comparable series of target and nontarget components were identified in each task, closely matching the range of components in the Schema. These findings illustrate the similarity of equiprobable and oddball processing and demonstrate that the Schema can apply to the classic oddball task. Nevertheless, task differences in behaviour and component amplitudes were evident, signifying important changes in target/nontarget demands reflecting stimulus probability.

4.2. Behavioural performance outcomes

The oddball task was associated with lower commission error rates and smaller RT ISDs, indicating that target responses were more accurate and controlled in the classic oddball task. Oddball RTs also tended to be longer; thus, taken together, these behavioural outcomes are consistent with the typical speed-accuracy trade-off found relative to target probability (Duncan-Johnson & Donchin, 1982; Miller, 1998).

4.3. Target processing outcomes

Eight ERP components were identified in relation to equiprobable targets, including (in latency order) N1-3, N1-1, PN, P2, N2c, P3b, and two slow-wave components (SW1, SW2). This series replicated our previous findings and the target profile in the young adult Schema (e.g., Barry, De Blasio, Fogarty, & Karamacoska, 2016; Borchard et al., 2015). The seven components linked to classic oddball target processing matched the series in the equiprobable task, excluding P2, which was not evident, suggesting that the processes underlying P2 were strongly abated when target probability decreased, in line with earlier research (Duncan-Johnson & Donchin, 1977; Spencer & Polich, 1999; N. Squires et al., 1975). This outcome may question the functional role of P2 in the Schema and auditory oddball task, suggesting that target categorisation could occur prior to, or independently of P2 processing. However, given the considerable amount of research relating P2 to sensory and perceptual processing (see e.g., Burkhard et al., 2019; Crowley & Colrain, 2004; Garcia-Larrea et al., 1992; Lijffijt et al., 2009; Shahin et al., 2005; Tong et al., 2009; Tremblay et al., 2001, 2014; Vaughan & Ritter, 1970), it is likely that oddball P2 was simply not extracted by PCA due to its lower amplitude or signal-to-noise ratio in the oddball task (see Section 4.6). In turn, the separation of equiprobable P2 could reflect its increased amplitude related to a greater signal-to-noise ratio and augmented perceptual processing as targets are presented more frequently in that task (e.g., enhanced sensory gating or short-term memory retrieval; Atienza et al., 2002; Lijffijt et al., 2009; Tong et al., 2009).

Across tasks, each target component demonstrated highly similar or equivalent amplitudes over time, except for N1-3 (Figure 4). The paired components were also highly similar topographically, although the correlation between the N2c components was notably weaker, perhaps due to greater N2c latency variability in the equiprobable data (see the double-peak in the raw ERPs at Fz; Figure 3). The topography of the target SW2− was also notably different between tasks, suggesting that distinct negative subcomponents were overlaying the equiprobable and oddball SW2+. This finding suggests that task-specific processing occurs towards the end of target trials in the SW time period, possibly reflecting some variation in the way that participants are evaluating performance, updating memory, or preparing for subsequent trials after infrequent targets. The remaining target components were remarkably similar across tasks, demonstrating that highly comparable processes are elicited by targets in the auditory equiprobable and classic oddball tasks.

4.3.1. Target processing demands

Target N1-1 and PN amplitudes were significantly larger in the classic oddball task, consistent with research illustrating a refractory period for N1 that results in lower amplitudes as target probability increases or target-to-target intervals decrease (see Budd et al., 1998; Coch et al., 2005; Duncan-Johnson & Donchin, 1977; Nelson & Lassman, 1968, 1973, 1977; Pereira et al., 2014; Polich et al., 1994; Steiner et al., 2014b, 2016; Spencer & Polich, 1999), and indicating that selective target identification was potentially more effortful when targets were rare (Näätänen, 1990). Contrary to our expectations and prior research (Nieuwenhuis et al., 2003; Spencer & Polich, 1999; N. Squires et al., 1975), target N2c did not differ with probability (Banquet et al., 1981; Polich et al., 1994), suggesting that each task demanded a similar amount of effort to categorise and direct further target response processing (Ritter et al., 1979).

Consistent with prior probability research, target P3b or "P300" amplitudes were larger in the classic oddball task (Dalbokova et al., 1990; Duncan-Johnson & Donchin, 1977, 1982; Hull & Harsh, 2001; Polich & Margala, 1997; Spencer & Polich, 1999; K. Squires et al., 1977; N. Squires et al., 1975). This can be interpreted from several perspectives. Larger P3b amplitudes could reflect greater neural inhibition linked to memory encoding (Polich, 2007), or index strategic changes associated with planning and control in the oddball task (Donchin & Coles, 1988). Alternatively, P3b could represent the reactivation of a stimulus-response relationship (i.e., target → button-press; Verleger et al., 2015), which requires more effort when that process is largely inactive.

The central target SW1+ was significantly smaller in the oddball, relative to the equiprobable task. Although the literature on SW functionality is relatively limited, positive SW activity is often thought to involve working memory or response evaluation (e.g., Friedman, 1984; García-Larrea & Cézanne-Bert, 1998; Ruchkin et al., 1990; Schmajuk et al., 2006), whereas late negative SW activity is often related to memory, control, and preparatory response processes in various cognitive tasks (Desmedt & Debecker, 1979; Mecklinger & Müller, 1996; Rohrbaugh et al., 1978; Ruchkin et al., 1988, 1990, 1995; Zickerick et al., 2020). In this study, the target SW1+ overlays the motor cortex and is larger contralateral to the responding hand, suggesting a potential link to motor cognition. The fact that it increases when participants must respond more frequently also supports this notion. Following this, and previous interpretations of SW activity, we suspect that the different subcomponents contributing to the target SW1 and SW2 may reflect an interplay between performance evaluation and the cognitive adjustments made to prepare for the next trial, but further research is necessary to test this proposal.

4.4. Nontarget processing outcomes

Seven components were related to nontarget processing in the auditory equiprobable and classic oddball tasks: N1-3, N1-1, PN, N2b, P3a, and nontarget SW1 and SW2. This component series closely replicates the nontarget ERP profile in the Sequential Processing Schema. However,

nontarget P1 was not extracted in either task (due to its small size; Barry & De Blasio, 2015) and nontarget SW1 and SW2 were identified instead of the LP. Nontarget SW2 could feature the LP (i.e., SW2+), however, its topography is substantially different to the global LP originally identified in Barry and De Blasio (2013). SW2 and LP will be considered separately here, but further research is needed to clarify these late components in the Schema.

The seven nontarget components demonstrated a highly similar or equivalent morphology in each task, except for N2b, which demonstrated more dissimilar factor loadings (Figure 6). However, the peak topography of each component (including N2b) was highly similar across tasks, although the oddball PN featured notably larger amplitudes at frontal sites. Overall, these outcomes demonstrate that successful nontarget processing elicits highly comparable processing stages in the equiprobable and classic oddball tasks.

The identification of a nontarget P3 in the current oddball task corroborates previous research identifying frequent-nontarget (i.e., standard) P3 components in similar tasks (e.g., Bruin & Wijers, 2002; Duncan-Johnson & Donchin, 1977; Kamp & Donchin, 2015; Kayser et al., 1998; McDonald et al., 2010; Rosenfeld et al., 2005; Spencer et al., 1999; N. Squires et al., 1975; Sutton et al., 1965; Tueting et al., 1971; Verleger & Berg, 1991; Verleger et al., 2016); although the specific factors underpinning P3 in these studies are not always clear (for some critique, see Barry, Steiner, & De Blasio, 2016; Dien et al., 2004). Identifying a frequent nontarget P3 might be considered unusual to some researchers, as P3 is often thought to be observable after targets and deviants only, as shown in novelty oddball tasks (e.g., Debener et al., 2005; Spencer et al., 2001). However, nontarget P3a might be evident in classic oddball tasks if targets and nontargets are highly similar, perhaps reflecting increased cognitive control requirements, or a shift in attention towards nontargets (Comerchero & Polich, 1999). Nontarget P3a amplitudes are also more central compared to the parietally dominant target P3b, and are negatively related to nontarget probability (Duncan-Johnson & Donchin, 1977; N. Squires et al., 1975). Accordingly, the apparent absence of P3a in other oddball studies could also be due to the higher nontarget probabilities, or P3 measures being limited to parietal sites. Alternatively, this may indicate a difference in the cognitive processing of frequent nontargets (i.e., standards) in classic two-stimulus and novelty variants of the oddball task, suggesting that researchers should be careful comparing the ERP results between these oddball variants.

4.4.1. Task effects on nontarget processing

As expected, nontarget N1-1, PN, and N2b were all significantly smaller in the classic oddball task, again demonstrating refractory and possibly faciliatory effects of increasing nontarget probability on stimulus identification (Duncan-Johnson & Donchin, 1977; Polich et al., 1994; Steiner et al., 2014b; N. Squires et al., 1975); as well as lower demands for inhibitory control as nontargets become standard and target motor response tendencies decrease (Bruin & Wijers, 2002; Miller, 1998; Nieuwenhuis et al., 2003). P3a amplitudes were also smaller in the

oddball task, consistent with our hypothesis, although this effect did not approach statistical significance, suggesting that the probability difference between the equiprobable and oddball tasks needed to be larger. However, the direction of that non-significant effect, and the significant N2b and behavioural outcomes found here, together corroborate previous research linking larger auditory N2b and P3a amplitudes to greater inhibitory demands and effortful control processing (e.g., Falkenstein et al., 1999; Fogarty et al., 2018).

Nontarget SW1+ and SW2− were both smaller in the oddball task, whereas the nontarget SW1− and SW2+ were increased, relative to their equiprobable counterparts. It is likely that these SW subcomponents represent a range of processes involved in nontarget performance evaluation and preparation for ensuing trials, similar to that proposed for the target SW1 and SW2 following prior SW research (e.g., Desmedt & Debecker, 1979; Rohrbaugh et al., 1978; Ruchkin et al., 1988, 1990, 1995).

4.5. Common elements across conditions

N1-3 amplitudes did not differ between tasks in either condition, supporting its link to a sensory process prior to stimulus identification (Näätänen & Picton, 1987). In contrast, N1-1 and PN both increased in amplitude as stimulus probability decreased, irrespective of the stimulus condition, indicating that these components represent subsequent processing stages, separate from the N1-3; perhaps involving higher order perceptual processes and selective attention, leading to stimulus categorisation (Näätänen, 1990; Näätänen & Picton, 1987). Following PN, stimulus-specific processing occurred, reflecting the different response requirements in the Schema (Figure 1). Each processing chain ended with two stimulus-specific SW components (SW1 and SW2), perhaps reflecting the evaluation, integration, and adjustment of task response processing. Further research is needed to test our current interpretation of these late components and illuminate their role in the young adult Schema, perhaps by examining their relationship with the response.

4.6. Further considerations

MMN was not extracted in this study, which is likely because the target probability was not low enough to elicit a significant mismatch response in these simple two-choice tasks. Indeed, the MMN guidelines set by Duncan et al. (2009) indicate that the optimal target probability in MMN-eliciting paradigms is ≤ 0.2. The large difference in auditory frequency between the stimuli used in this study could also have shifted MMN latencies towards the N100 (Justen & Herbert, 2018), and this potential overlap could have made it more difficult to extract the MMN separately, particularly if it was very small.

The present PN outcomes contradict what is expected by Attentional-Trace Theory, which suggests that PN reflects electrocortical activity generated as new stimuli are compared to a neuronal representation of the target (Näätänen, 1982). This representation (and thus, PN) has been shown to diminish with a lack of sensory reinforcement, which occurs when the relevant stimuli are infrequent (Alho et al., 1990); however, here PN amplitudes increased as stimulus

probabilities decreased, irrespective of the condition. This could question Attentional-Trace Theory. Alternatively, the PCA-derived PN might not be representative of the traditional PN, which is normally measured from difference waveforms (i.e., Nd; Näätänen, 1990).

Both PN and MMN are traditionally isolated from the difference between target and nontarget ERP data (e.g., Alho et al., 1990), which can provide valuable insight. However, this subtraction process can also cancel out relevant data within conditions (Näätänen, 1982). The subtraction approach does not clearly account for the ERP variance associated with overlapping ERP components either, resulting in unknown levels of error in difference waveforms (Ouyang et al., 2013). In contrast, PCA separates components based on the underlying patterns in the ERP data, which should still extract and isolate components like MMN if they carry enough unique variance. A limitation of this study was that we did not include a nose-reference to explore and validate MMN further. To our knowledge, no research has examined the comparability of PCA-derived MMN components with those measured from difference-waveforms; this would be useful to consider in future research to determine if MMN can be extracted separately or if its variance loads onto other factors derived from the typical target and nontarget waveforms.

The use of PCA to decompose the ERP data is considered a strength of this study. However, a possible limitation to be considered is the use of orthogonal *Varimax* rotation. Varimax-rotated factor loadings may be biased by the orthogonality constraint (see Scharf & Nestler, 2018). This bias can inflate factor cross-loadings, which may be reflected in the temporal overlap of the loadings in this study, and is perhaps most apparent in the long tail of the N1-1 overlapping later factors. The absence of oddball P2 may also be explained by this as Varimax might achieve greater simple structure and orthogonality by misallocating ERP variance (Dien, 1998; Dien et al., 2005); that is, P2 may have been subsumed within other overlapping factors, particularly if it was less prominent in the oddball task. Accordingly, the duration of factors and their interpretations should be considered with some caution.

In particular, the SW1 and SW2 outcomes should be generalised tentatively, as it is not clear what these factors represent or how they relate to SW factors identified in previous studies. The topographies of SW1 and SW2 do not bear any obvious similarity to that described for the 'classic' frontally-negative and parietally-positive SW, even when the subcomponents of that component are delineated using methods like PCA (e.g., Loveless et al., 1987; Spencer et al., 2001; Steiner et al., 2013; Strüber & Polich, 2002). Instead, SW1 and SW2 resemble other late frontal, parietal, or frontoparietal negativities that are often linked to memory processing, evaluation, and preparation in similar paradigms (Desmedt & Debecker, 1979; Rohrbaugh et al., 1978; Ruchkin et al., 1988, 1990, 1995). Hence, we put forward a tentative interpretation regarding the functionality of the components labelled as SW1 and SW2 in this study, which aligns with this view in the literature and the current findings. However, as mentioned, it is also

possible that these factors are somewhat distorted by Varimax constraints, and systematic testing is needed to explore the stability of SW1 and SW2 using different techniques and task designs.

As mentioned in Chapter 1, the correct factor solution cannot be known, and despite the potential limitations of Varimax rotation the factor solutions in this study provide a sensible model of numerous ERP components in the broader literature. Strict factor orthogonality may not be realistic (Dien et al., 2005), however, the current results are considered to provide a simple and stable account of the ERP data in this task. Further research comparing the factor series output by different rotations (e.g., orthogonal vs. oblique) would help to highlight the potential biases in each solution and facilitate the interpretation of these factors and the development of a holistic ERP data-driven processing schema for these paradigms.

4.7. Conclusion

This investigation showed that a highly similar range of ERP components is elicited in healthy young adults completing both the auditory equiprobable and classic oddball tasks. These components also closely replicated Barry and De Blasio's (2013) Sequential Processing Schema (as updated by Fogarty et al., 2018), demonstrating that it can apply to the auditory classic oddball as well as its formative equiprobable task. These findings illustrate a high level of comparability between these two tasks, showing that classic oddball target and nontarget processing closely parallels that in the equiprobable task; though there are clear variations in the task demands illustrated by the differing component amplitudes and behaviour. This indicates that the equiprobable task can be used as an efficient alternative to the classic oddball paradigm. More importantly, these outcomes will facilitate the integration and progression of the ERP theory and research linked to equiprobable and oddball tasks, particularly in relation to the Sequential Processing Schema.

References

Alho, K., Lavikainen, J., Reinikainen, K., Sams, M., & Näätänen, R. (1990). Event-related brain potentials in selective listening to frequent and rare stimuli. *Psychophysiology*, *27*(1), 73–86. https://doi.org/10.1111/j.1469-8986.1990.tb02183.x

Atienza, M., Cantero, J. L., & Dominguez-Marin, E. (2002). The time course of neural changes underlying auditory perceptual learning. *Learning & Memory*, *9*(3), 138–150. https://doi.org/10.1101/lm.46502

Banquet, J. P., Renault, B., & Lesèvre, N. (1981). Effect of task and stimulus probability on evoked potentials. *Biological Psychology*, *13*, 203–214. https://doi.org/10.1016/0301-0511(81)90036-3

Barry, R. J., & De Blasio, F. M. (2013). Sequential processing in the equiprobable auditory Go/NoGo task: A temporal PCA study. *International Journal of Psychophysiology*, *89*(1), 123–7. https://doi.org/10.1016/j.ijpsycho.2013.06.012

Barry, R. J., & De Blasio, F. M. (2015). Performance and ERP components in the equiprobable go/no-go task: Inhibition in children. *Psychophysiology*, *52*(9), 1228–1237. https://doi.org/10.1111/psyp.12447

Barry, R. J., De Blasio, F. M., & Borchard, J. P. (2014). Sequential processing in the equiprobable auditory Go/NoGo task: Children vs. adults. *Clinical Neurophysiology*, *125*(10), 1995–2006. https://doi.org/10.1016/j.clinph.2014.02.018

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2014). Caffeine effects on ERP components and performance in an equiprobable auditory Go/NoGo task. *Journal of Caffeine Research*, *4*(3), 83–92. https://doi.org/10.1089/jcr.2014.0011

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2016). Sequential processing in younger and older adults in the equiprobable auditory Go/NoGo task. *Clinical Neurophysiology*, *127*(5), 2273–2285. https://doi.org/10.1016/j.clinph.2016.02.010

Barry, R. J., De Blasio, F. M., De Pascalis, V., & Karamacoska, D. (2014). Preferred EEG brain states at stimulus onset in a fixed interstimulus interval equiprobable auditory Go/NoGo task: A definitive study. *International Journal of Psychophysiology*, *94*(1), 42–58. https://doi.org/10.1016/j.ijpsycho.2014.07.005

Barry, R. J., De Blasio, F. M., & Fogarty, J. S. (2018). A processing schema for children in the auditory equiprobable Go/NoGo task: ERP components and behaviour. *International Journal of Psychophysiology*, *123*, 74–79. https://doi.org/10.1016/j.ijpsycho.2017.10.014

Barry, R. J., De Blasio, F. M., Fogarty, J. S., & Karamacoska, D. (2016). ERP Go/NoGo condition effects are better detected with separate PCAs. *International Journal of Psychophysiology*, *106*, 50–64. https://doi.org/10.1016/j.ijpsycho.2016.06.003

Barry, R. J., Kirkaikul, S., & Hodder, D. (2000). EEG alpha activity and the ERP to target

stimuli in an auditory oddball paradigm. *International Journal of Psychophysiology, 39*(1), 39–50. https://doi.org/10.1016/S0167-8760(00)00114-8

Barry, R. J., Steiner, G. Z., & De Blasio, F. M. (2016). Reinstating the Novelty P3. *Scientific Reports, 6,* Article 31200. https://doi.org/10.1038/srep31200

Borchard, J. P., Barry, R. J., & De Blasio, F. M. (2015). Sequential processing in an auditory equiprobable Go/NoGo task with variable interstimulus interval. *International Journal of Psychophysiology, 97*(2), 145–52. https://doi.org/10.1016/j.ijpsycho.2015.05.010

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*(3), 624–652. https://doi.org/10.1037/0033-295X.108.3.624

Brigham, J., Herning, R. I., & Moss, H. B. (1995). Event-related potentials and alpha synchronization in preadolescent boys at risk for psychoactive substance use. *Biological Psychiatry, 37*(12), 834–846. https://doi.org/10.1016/0006-3223(94)00218-R

Bruin, K. J., & Wijers, A. A. (2002). Inhibition, response mode, and stimulus probability: A comparative event-related potential study. *Clinical Neurophysiology, 113*(7), 1172–1182. https://doi.org/10.1016/S1388-2457(02)00141-4

Budd, T. W., Barry, R. J., Gordon, E., Rennie, C., & Michie, P. T. (1998). Decrement of the N1 auditory event-related potential with stimulus repetition: habituation vs. refractoriness. *International Journal of Psychophysiology, 31*(1), 51–68. https://doi.org/10.1016/s0167-8760(98)00040-3

Burkhard, A., Elmer, S., & Jäncke, L. (2019). Early tone categorization in absolute pitch musicians is subserved by the right-sided perisylvian brain. *Scientific reports, 9*(1), 1–14. https://doi.org/10.1038/s41598-018-38273-0

Coch, D., Skendzel, W., & Neville, H. J. (2005). Auditory and visual refractory period effects in children and adults: An ERP study. *Clinical Neurophysiology, 116*(9), 2184–2203. https://doi.org/10.1016/j.clinph.2005.06.005

Coles, M. G., Gratton, G., Bashore, T. R., Eriksen, C. W., & Donchin, E. (1985). A psychophysiological investigation of the continuous flow model of human information processing. *Journal of Experimental Psychology: Human Perception and Performance, 11*(5), 529–553. https://doi.org/10.1037/0096-1523.11.5.529

Comerchero, M. D., & Polich, J. (1999). P3a and P3b from typical auditory and visual stimuli. *Clinical Neurophysiology, 110*(1), 24–30. https://doi.org/10.1016/S0168-5597(98)00033-1

Courchesne, E., Hillyard, S. A., & Galambos, R. (1975). Stimulus novelty, task relevance and the visual evoked potential in man. *Electroencephalography and Clinical Neurophysiology, 39*(2), 131–143. https://doi.org/10.1016/0013-4694(75)90003-6

Croft, R. J., & Barry, R. J. (2000). Removal of ocular artifact from the EEG: A review.

Neurophysiologie Clinique, *30*(1), 5–19. https://doi.org/10.1016/S0987-7053(00)00055-1

Crowley, K. E., & Colrain, I. M. (2004). A review of the evidence for P2 being an independent component process: Age, sleep and modality. *Clinical Neurophysiology*, *115*(4), 732–744. https://doi.org/10.1016/j.clinph.2003.11.021

Dalbokova, D., Gille, H. G., & Ullsperger, P. (1990). Amplitude variations in P300 component due to unpredictable stepwise change of stimulus probability. *International Journal of Psychophysiology*, *10*(1), 33–38. https://doi.org/10.1016/0167-8760(90)90042-c

Debener, S., Ullsperger, M., Siegel, M., Fiehler, K., Von Cramon, D. Y., & Engel, A. K. (2005). Trial-by-trial coupling of concurrent electroencephalogram and functional magnetic resonance imaging identifies the dynamics of performance monitoring. *Journal of Neuroscience*, *25*(50), 11730–11737. https://doi.org/10.1523/JNEUROSCI.3286-05.2005

Desmedt, J. E., & Debecker, J. (1979). Slow potential shifts and decision P350 interactions in tasks with random sequences of near-threshold clicks and finger stimuli delivered at regular intervals. *Electroencephalography and Clinical Neurophysiology*, *47*, 671–679. https://doi.org/10.1016/0013-4694(79)90294-3

Dien, J. (1998). Addressing misallocation of variance in principal components analysis of event-related potentials. *Brain Topography*, *11*(1), 43–55. https://doi.org/10.1023/A

Dien, J. (2010). The ERP PCA Toolkit: An open source program for advanced statistical analysis of event-related potential data. *Journal of Neuroscience Methods*, *187*(1), 138–145. https://doi.org/10.1016/j.jneumeth.2009.12.009

Dien, J., Beal, D. J., & Berg, P. (2005). Optimizing principal components analysis of event-related potentials: matrix type, factor loading weighting, extraction, and rotations. *Clinical Neurophysiology*, *116*(8), 1808–1825. https://doi.org/10.1016/j.clinph.2004.11.025

Dien, J., & Frishkoff, G. A. (2005). Introduction to principal components analysis of event-related potentials. In T. Handy (Ed.), *Event-related potentials: A methods handbook* (pp. 189–208). Cambridge, MA: MIT Press.

Dien, J., Spencer, K. M., & Donchin, E. (2004). Parsing the late positive complex: mental chronometry and the ERP components that inhabit the neighborhood of the P300. *Psychophysiology*, *41*(5), 665–678. https://doi.org/10.1111/j.1469-8986.2004.00193.x

Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioural and Brain Sciences. 11*(3), 357–374. https://doi.org/10.1017/S0140525X00058027

Duncan, C. C., Barry, R. J., Conolly, J. F., Fischer, C., Michie, P. T., Näätänen, R., Polich, J., Reinvang, I., & Van Petten, C. (2009). Event-related potentials in clinical research:

Guidelines for eliciting, recording, and quantifying mismatch negativity, P300, and N400. *Clinical Neurophysiology*, *120*(11), 1883–1908. https://doi.org/10.1016/j.clinph.2009.07.045

Duncan-Johnson, C. C., & Donchin, E. (1977). On quantifying surprise: The variation of event-related potentials with subjective probability. *Psychophysiology*, *14*(15), 456–467. https://doi.org/10.1111/j.1469-8986.1977.tb01312.x

Duncan-Johnson, C. C., & Donchin, E. (1982). The P300 component of the event-related brain potential as an index of information processing. *Biological Psychology*, *14*(1–2), 1–52. https://doi.org/10.1016/0301-0511(82)90016-3

Eliades, S. J., Crone, N. E., Anderson, W. S., Ramadoss, D., Lenz, F. A., & Boatman-Reich, D. (2014). Adaptation of high-gamma responses in human auditory association cortex. *Journal of Neurophysiology*, *112*(9), 2147–2163. https://doi.org/10.1152/jn.00207.2014

Escera, C., Alho, K., Winkler, I., & Näätänen, R. (1998). Neural mechanisms of involuntary attention. *Journal of Cognitive Neuroscience*, *10*(5), 590–604. https://doi.org/10.1162/089892998562997

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica*, *101*(2–3), 267–291. https://doi.org/10.1016/S0001-6918(99)00008-6

Fitzgerald, P. G., & Picton, T. W. (1981). Temporal and sequential probability in evoked potential studies. *Canadian Journal of Psychology*, *35*(2), 188–200. https://doi.org/10.1037/h0081154

Fogarty, J. S., Barry, R. J., De Blasio, F. M., & Steiner, G. Z. (2018). ERP components and behavior in the auditory equiprobable go/no-go task: Inhibition in young adults. *Psychophysiology*, *55*(7), Article e13065. https://doi.org/10.1111/psyp.13065

Friedman, D. (1984). P300 and slow wave: the effects of reaction time quartile. *Biological Psychology*, *18*, 49–71. https://doi.org/10.1016/0301-0511(84)90028-0

García-Larrea, L., & Cézanne-Bert, G. (1998). P3, positive slow wave and working memory load: a study on the functional correlates of slow wave activity. *Electroencephalography and Clinical Neurophysiology*, *108*, 260–273. https://doi.org/10.1016/s0168-5597(97)00085-3

García-Larrea, L., Lukaszewicz, A. C., & Mauguire, F. (1992). Revisiting the oddball paradigm. Non-target vs neutral stimuli and the evaluation of ERP attentional effects. *Neuropsychologia*, *30*(8), 723–741. https://doi.org/10.1016/0028-3932(92)90042-K

Hull, J., & Harsh, J. (2001). P300 and sleep-related positive waveforms (P220, P450, and P900) have different determinants. *European Sleep Research Society*, *10*, 9–17. https://doi.org/10.1046/j.1365-2869.2001.00238.x

Justen, C., & Herbert, C. (2018). The spatio-temporal dynamics of deviance and target detection

in the passive and active auditory oddball paradigm: A sLORETA study. *BMC Neuroscience, 19*(1), 1–18. https://doi.org/10.1186/s12868-018-0422-3

Kamp, S.-M., & Donchin, E. (2014). ERP and pupil responses to deviance in an oddball paradigm. *Psychophysiology, 52*(4), 460–471. https://doi.org/10.1111/psyp.12378

Karamacoska, D., Barry, R. J., & Steiner, G. Z. (2017). Resting state intrinsic EEG impacts on go stimulus-response processes. *Psychophysiology, 54*(6), 894–903. https://doi.org/10.1111/psyp.12851

Karamacoska, D., Barry, R. J., Steiner, G. Z., Coleman, E. P., & Wilson, E. J. (2018). Intrinsic EEG and task-related changes in EEG affect Go/NoGo task performance. *International Journal of Psychophysiology, 125*, 17–28. https://doi.org/10.1016/j.ijpsycho.2018.01.015

Kayser, J., & Tenke, C. E. (2003). Optimizing PCA methodology for ERP component identification and measurement: Theoretical rationale and empirical evaluation. *Clinical Neurophysiology, 114*(12), 2307–2325. https://doi.org/10.1016/S1388-2457(03)00241-4

Kayser, J., Tenke, C. E., & Bruder, G. E. (1998). Dissociation of brain ERP topographies for tonal and phonetic oddball tasks. *Psychophysiology, 35*(5), 576–590. https://doi.org/10.1017/S0048577298970214

Key, A. P., & Yoder, P. J. (2013). Equiprobable and oddball paradigms: two approaches for documenting auditory discrimination. *Developmental Neuropsychology, 38*(6), 402–17. https://doi.org/10.1080/87565641.2012.718819

Lijffijt, M., Lane, S. D., Meier, S. L., Boutros, N. N., Burroughs, S., Steinberg, J. L., Moeller, F. G., & Swann, A. C. (2009). P50, N100, and P200 sensory gating: Relationships with behavioral inhibition, attention, and working memory. *Psychophysiology, 46*(5), 1059–1068. https://doi.org/10.1111/j.1469-8986.2009.00845.x

Lorenzo-Seva, U., & ten Berge, J. M. F. (2006). Tucker's congruence coefficient as a meaningful index of factor similarity. *Methodology, 2*(2), 57–64. https://doi.org/10.1027/1614-2241.2.2.57

Loveless, N. E., Simpson, M., & Näätänen, R. (1987). Frontal negative and parietal positive components of the slow wave dissociated. *Psychophysiology, 24*(3), 340–345. https://doi.org/10.1111/j.1469-8986.1987.tb00305.x

McDonald, C. G., Gabbay, F. H., Rietschel, J. C., & Duncan, C. C. (2010). Evidence for a new late positive ERP component in an attended novelty oddball task. *Psychophysiology, 47*(5), 809–813. https://doi.org/10.1111/j.1469-8986.2010.00986.x

Mecklinger, A., & Müller, N. (1996). Dissociations in the processing of "what" and "where" information in working memory: An event-related potential analysis. *Journal of Cognitive Neuroscience, 8*(5), 453–473. https;//doi.org/10.1162/jocn.1996.8.5.453

Miller, J. (1998). Effects of stimulus-response probability on choice reaction time: Evidence

from the lateralized readiness potential. *Journal of Experimental Psychology: Human Perception and Performance, 24*(5), 1521–1534. https://doi.org/10.1037/0096-1523.24.5.1521

Näätänen, R. (1982). Processing negativity: An evoked-potential reflection of selective attention. *Psychological Bulletin, 92*(3), 605–640. https://doi.org/10.1037/0033-2909.92.3.605

Näätänen, R. (1990). The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. *Behavioral and Brain Sciences, 13*(2), 201–233. https://doi.org/10.1017/S0140525X00078407

Näätänen, R., Paavilainen, P., Rinne, T., & Alho, K. (2007). The mismatch negativity (MMN) in basic research of central auditory processing: A review. *Clinical Neurophysiology, 118*(12), 2544–2590. https://doi.org/10.1016/j.clinph.2007.04.026

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24*(4), 375–425. https://doi.org/10.1111/j.1469-8986.1987.tb00311.x

Nelson, D. A., Lassman, F. M. (1968). Effects of inter signal interval on the human auditory evoked response. *Journal of the Acoustical Society of America, 44*(6), 1529–1532. https://doi.org/10.1121/1.1911292

Nelson, D. A., & Lassman, F. M. (1973). Combined effects of recovery period and stimulus intensity on the human auditory evoked vertex response. *Journal of Speech and Hearing Research, 16*(2), 297–308. https://doi.org/10.1044/jshr.1602.297

Nelson, D. A., & Lassman, F. M. (1977). Re-examination of the effects of periodic and aperiodic stimulation on the auditory-evoked vertex response. *International Journal of Audiology, 16*(5), 409–418. https://doi.org/10.3109/00206097709071854

Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective & Behavioral Neuroscience, 3*(1), 17–26. https://doi.org/10.3758/CABN.3.1.17

O'Brien, R. G., & Kaiser, M. K. (1985). MANOVA method for analyzing repeated measures designs: An extensive primer. *Psychological Bulletin, 97*(2), 316–333. https://doi.org/10.1037/0033-2909.97.2.316

Ouyang, G., Schacht, A., Zhou, C., & Sommer, W. (2013). Overcoming limitations of the ERP method with Residue Iteration Decomposition (RIDE): A demonstration in go/no-go experiments. *Psychophysiology, 50*(3), 253–265. https://doi.org/10.1111/psyp.12004

Pereira, D. R., Cardoso, S., Ferreira-Santos, F., Fernandes, C., Cunha-Reis, C., Paiva, T. O., Almeida, P. R., Silveira, C., Barbosa, F., & Marques-Teixeira, J. (2014). Effects of inter-stimulus interval (ISI) duration on the N1 and P2 components of the auditory

event-related potential. *International Journal of Psychophysiology*, *94*(3), 311–318. https://doi.org/10.1016/j.ijpsycho.2014.09.012

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*(10), 2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Polich, J., Eischen, S. E., & Collins, G. E. (1994). P300 from a single auditory stimulus. *Electroencephalography and Clinical Neurophysiology/ Evoked Potentials*, *92*(3), 253–261. https://doi.org/10.1016/0168-5597(94)90068-X

Polich, J., & Margala, C. (1997). P300 and probability: Comparison of oddball and single-stimulus paradigms. *International Journal of Psychophysiology*, *25*(2), 169–176. https://doi.org/10.1016/S0167-8760(96)00742-8

Ritter, W., Simson, R., Vaughan, H. G., & Friedman, D. (1979). A brain event related to the making of a sensory discrimination. *Science*, *203*(4387), 1358–1361. https://doi.org/10.1126/science.424760

Rohrbaugh, J. W., Syndulko, K., & Lindsley, D. B. (1978). Cortical slow negative waves following non-paired stimuli: Effects of Task Factors. *Electroencephalography and Clinical Neurophysiology*, *45*(5), 551–567. https://doi.org/10.1016/0013-4694(78)90156-6

Rosenfeld, J. P., Biroschak, J. R., Kleschen, M. J., & Smith, K. M. (2005). Subjective and objective probability effects on P300 amplitude revisited. *Psychophysiology*, *42*(3), 356–359. https://doi.org/10.1111/j.1469-8986.2005.00283.x

Ruchkin, D. S., Canoune, H. L., Johnson, R., & Ritter, W. (1995). Working memory and preparation elicit different patterns of slow wave event-related brain potentials. *Psychophysiology*, *32*(4), 399–410. https://doi.org/10.1111/j.1469-8986.1995.tb01223.x

Ruchkin, D. S., Johnson, R., Canoune, H., & Ritter, W. (1990). Short-term memory storage and retention: an event-related brain potential study. *Electroencephalography and Clinical Neurophysiology*, *76*(5), 419–439. https://doi.org/10.1016/0013-4694(90)90096-3

Ruchkin, D. S., Johnson, R., Mahaffey, D., & Sutton, S. (1988). Toward a functional categorization of slow waves. *Psychophysiology*, *25*(3), 339–353. https://doi.org/10.1111/j.1469-8986.1988.tb01253.x

Scharf, F., & Nestler, S. (2018). Principles behind variance misallocation in temporal exploratory factor analysis for ERP data: Insights from an inter-factor covariance decomposition. *International Journal of Psychophysiology*, *128*, 119–136. https://doi.org/10.1016/j.ijpsycho.2018.03.019

Schmajuk, M., Liotti, M., Busse, L., & Woldorff, M. G. (2006). Electrophysiological activity underlying inhibitory control processes in normal adults. *Neuropsychologia*, *44*(3), 384–395. https://doi.org/10.1016/j.neuropsychologia.2005.06.005

Shahin, A., Roberts, L. E., Pantev, C., Trainor, L. J., & Ross, B. (2005). Modulation of P2

auditory-evoked responses by the spectral complexity of musical sounds. *NeuroReport, 16*(16), 1781–1785. https://doi.org/10.1097/01.wnr.0000185017.29316.63

Spencer, K. M., Dien, J., & Donchin, E. (2001). Spatiotemporal analysis of the late ERP responses to deviant stimuli. *Psychophysiology, 38*(2), 343–358. https://doi.org/10.1111/1469-8986.3820343

Spencer, K. M., & Polich, J. (1999). Poststimulus EEG spectral analysis and P300: attention, task and probability. *Psychophysiology, 36*(2), 220–232. https://doi.org/10.1111/1469-8986.3620220

Squires, K. C., Donchin, E., Herning, R. I., & McCarthy, G. (1977). On the influence of task relevance and stimulus probability on event-related-potential components. *Electroencephalography and Clinical Neurophysiology, 42*(1), 1–14. https://doi.org/10.1016/0013-4694(77)90146-8

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology, 38*(4), 387–401. https://doi.org/10.1016/0013-4694(75)90263-1

Steiner, G. Z., Barry, R. J., & Gonsalvez, C. J. (2013). Can working memory predict target-to-target interval effects in the P300? *International Journal of Psychophysiology, 89*(3), 399–408. https://doi.org/10.1016/j.ijpsycho.2013.07.011

Steiner, G. Z., Barry, R. J., & Gonsalvez, C. J. (2014a). Nontarget-to-nontarget interval determines the nontarget P300 in an auditory equiprobable Go/NoGo task. *International Journal of Psychophysiology, 92*(3), 113–121. https://doi.org/10.1016/j.ijpsycho.2014.03.010

Steiner, G. Z., Barry, R. J., & Gonsalvez, C. J. (2014b). Stimulus-to-matching-stimulus interval influences N1, P2, and P3b in an equiprobable Go/NoGo task. *International Journal of Psychophysiology, 94*(1), 59–68. https://doi.org/10.1016/j.ijpsycho.2014.07.003

Steiner, G. Z., Barry, R. J., & Gonsalvez, C. J. (2016). Sequential processing and the matching-stimulus interval effect in ERP components: An exploration of the mechanism using multiple regression. *Frontiers in Human Neuroscience, 10*, 1–14. https://doi.org/10.3389/fnhum.2016.00339

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica*, *30*, 276–315. https://doi.org/10.1016/0001-6918(69)90055-9

Strüber, D., & Polich, J. (2002). P300 and slow wave from oddball and single-stimulus visual tasks: inter-stimulus interval effects. *International Journal of Psychophysiology, 45*(3), 187–196. https://doi.org/10.1016/s0167-8760(02)00071-5

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoke-potential correlates of stimulus uncertainty. *Science, 150*(3700), 1187–1188.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). England: Pearson Education Limited.

Tong, Y., Melara, R. D., & Rao, A. (2009). P2 enhancement from auditory discrimination training is associated with improved reaction times. *Brain Research, 1297,* 80–88. https://doi.org/10.1016/j.brainres.2009.07.089

Tremblay, K. L., Kraus, N., McGee, T., Ponton, C., & Otis, B. (2001). Central auditory plasticity: changes in the N1-P2 complex after speech-sound training. *Ear and Hearing*, *22*(2), 79–90. https://doi.org/10.1097/00003446-200104000-00001

Tremblay, K. L., Ross, B., Inoue, K., McClannahan, K., & Collet, G. (2014). Is the auditory evoked P2 response a biomarker of learning? *Frontiers in Systems Neuroscience*, *8*, Article 28. https://doi.org/10.3389/fnsys.2014.00028

Tucker, L. R. (1951). A method for synthesis of factor analysis studies (Personnel Research Section Report No. 984). Washington, DC: Department of the Army.

Tueting, P., Sutton, S., & Zubin, J. (1971). Quantitative evoked potential correlates of the probability of events. *Psychophysiology*, *7*(3), 385–394.

Vaughan, H. G., Jr., & Ritter, W. (1970). The sources of auditory evoked responses recorded from the human scalp. *Electroencephalography and Clinical Neurophysiology, 28*(4), 360–367. https://doi.org/10.1016/0013-4694(70)90228-2

Verleger, R., & Berg, P. (1991). The waltzing oddball. *Psychophysiology*, *28*(4), 468–477. https://doi.org/10.1111/j.1469-8986.1991.tb00733.x

Verleger, R., Grauhan, N., & Śmigasiewicz, K. (2016). Go and no-go P3 with rare and frequent stimuli in oddball tasks: A study comparing key-pressing with counting. *International Journal of Psychophysiology*, *110*, 128–136. https://doi.org/10.1016/j.ijpsycho.2016.11.009

Verleger, R., Hamann, L. M., Asanowicz, D., & Śmigasiewicz, K. (2015). Testing the S-R link hypothesis of P3b: The oddball effect on S1-evoked P3 gets reduced by increased task relevance of S2. *Biological Psychology, 108*, 25–35. https://doi.org/10.1016/j.biopsycho.2015.02.010

Zickerick, B., Thönes, S., Kobald, S. O., Wascher, E., Schneider, D., & Küper, K. (2020). Differential effects of interruptions and distractions on working memory processes in an ERP study. *Frontiers in Human Neuroscience*, *14*, Article 84. https://doi.org/10.3389/fnhum.2020.00084

Chapter 3. The First 250 ms of Auditory Processing: No Evidence of Early Processing Negativity in the Go/NoGo Task

Foreword

Through the vagaries of the peer review system, this chapter, corresponding to Experiment 2, was the third accepted paper from this thesis. It compared the sequential processing and behaviour in traditional (frequent Go) and equiprobable Go/NoGo tasks. Following the probability effects identified in Chapter 2, it was suspected that PN may have been misidentified in much of the previous Go/NoGo PCA research, which has important implications for the conceptualisation of Go/NoGo processing. Hence, Chapter 3 concentrated on clarifying the ERP components in the first 250 ms of auditory Go/NoGo processing, with a particular focus on the factor previously identified as the Go/NoGo PN. In this chapter, the labelling of the N1 components changed to follow the nomenclature in McCallum and Curry (1980), reflecting conceptual developments adopted during this study. Minor changes were made to the accepted article for this thesis and its final publication in the journal, *Scientific Reports*. A copy of the published article is printed in Appendix C for reference.

Citation

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Author Contributions

JSF conceptualised this study. JSF performed the data collection, analyses, and interpretation of the outcomes under the supervision of RJB and GZS. The journal article was drafted and finalised by JSF following critical revisions provided by RJB and GZS. All authors approved the final article prior to submission.

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Abstract

Past evidence of an early Processing Negativity in auditory Go/NoGo event-related potential (ERP) data suggests that young adults proactively process sensory information in two-choice tasks. This study aimed to clarify the occurrence of Go/NoGo Processing Negativity and investigate the ERP component series related to the first 250 ms of auditory processing in two Go/NoGo tasks differing in target probability. ERP data related to each task were acquired from 60 healthy young adults (M_{age} = 20.4, *SD* = 3.1 years). Temporal principal components analyses were used to decompose ERP data in each task. Statistical analyses compared component amplitudes between stimulus type (Go vs. NoGo) and probability (High vs. Low). Neuronal source localisation was also conducted for each component. Processing Negativity was not evident; however, P1, N1a, N1b, and N1c were identified in each task, with Go P2 and NoGo N2b. The absence of Processing Negativity in this study indicated that young adults do not proactively process targets to complete the Go/NoGo task and/or questioned Processing Negativity's conceptualisation. Additional analyses revealed stimulus-specific processing as early as P1, and outlined a complex network of active neuronal sources underlying each component, providing useful insight into Go and NoGo information processing in young adults.

Keywords: auditory processing, event-related potentials, Go/NoGo, Processing Negativity, source localisation

1. Introduction

The Go/NoGo task requires participants to respond quickly and accurately to Go (target) stimuli, while making no response to NoGo (nontarget) stimuli. Like other two-choice tasks (e.g., oddball tasks), this involves complex sensory, perceptual, and cognitive processing to discriminate between stimuli, and to regulate or control behaviour. However, Go/NoGo tasks are unique in that they provide a response set specifically for motor inhibition, the ability to suppress active or prepotent motor responses (Gomez et al., 2007; Wessel, 2018). The purpose of this study was to clarify the early information and control processing in auditory Go/NoGo tasks by analysing the series of electroencephalographic (EEG) event-related potential (ERP) components related to the first 250 ms of Go/NoGo processing.

The first 250 ms of auditory Go/NoGo processing is generally associated with four ERP components: P1, N1, P2, and N2. P1 is a small frontal scalp positivity that peaks ~ 50 ms after the onset of auditory stimuli, reflecting neuronal activity primarily generated in the temporal lobe and prefrontal cortex (Brodmann's Area [BA] 2, 6, 22, and 24: Grunwald et al., 2003; Korzyukov, et al., 2007). P1 (or P50) is generally associated with sensory gating, an early selection mechanism involving the automatic filtering of sensory stimuli to facilitate relevant or targeted information processing (Alho et al., 1994; Freedman et al., 1987; Knight et al., 1989; Lijffijt et al., 2009).

N1 is a large frontocentral negativity that peaks ~ 100 ms poststimulus, involving a complex of sensory components, including a small and diffuse N1a that peaks ~ 75 ms poststimulus, a frontocentral N1b at ~ 100 ms, and a temporal N1c at ~ 150 ms after stimulus onset (Bender et al., 2006; Knight et al., 1988; McCallum & Curry, 1980; Nielsen-Bohlman et al., 1991; Timm et al., 2013; Wolpaw & Penry, 1975; Woods, 1995). These N1 components are also referred to as N1-3, N1-1, and N1-2, respectively, representing the "true" N1 components in Näätänen and Picton's (1987) review of the N1. N1a and N1c are also considered part of the T-complex (or T-wave), a double-peaked N1 waveform that is evident at the temporal scalp electrode sites (Woods, 1995).

N1 generators are located mostly in the superior temporal plane, including the primary and secondary auditory cortices (BA 41 and 42) and auditory association area (BA 22: Lü et al., 1992; Martin et al., 2007; Näätänen & Picton, 1987; Pantev et al., 1995; Woods, 1995). However, N1 may also have sources in the frontal lobe (BA 9, 10, 24, 32, and 33: Dien et al., 1997; Grau et al., 2007; Picton et al., 1999), supporting links between N1 and attention (Giard et al., 1994; Näätänen, 1988), or response selection (Bender et al., 2006; Filipović et al., 2000; Kirmizi-Alsan et al., 2006). N1 is generally considered to mark stimulus detection, and perhaps later stages of sensory gating in conjunction with P2 (Lijffijt et al., 2009; Joos et al., 2014).

P2 is a central positivity that peaks ~ 200 ms poststimulus, reflecting neuronal activity in the vicinity of Heschl's gyrus, slightly anterior to the N1 generators (Lütkenhöner & Steinsträter, 1998; Ross & Tremblay, 2009; Woods et al., 1993). Alternate sources have also been suggested

for P2, including the reticular activating system and BA 22 (Crowley & Colrain, 2004; Rif et al., 1991).

The functional significance of P2 is not clear, although suggestions have been made that it is linked to higher-level perceptual processes involved in target identification (Crowley & Colrain, 2004). This corresponds with previous auditory ERP research illustrating differential Go and NoGo processing after N1, marked by the Go-specific P2 and NoGo-specific N2b (Borchard et al., 2015). N2b is a frontal negativity that peaks ~ 200 ms after NoGo stimulus onset, reflecting neuronal activity in the anterior cingulate cortex (BA 32 and 33) commonly associated with cognitive control (Botvinick et al., 2004; Folstein & Van Petten, 2008; Gratton et al., 2018).

In auditory discrimination tasks, the automatic sensory components may be overlapped by Processing Negativity (PN), an endogenous slow wave associated with selective attention (Näätänen, 1982). PN is considered to index a matching process between attended sensory input and an actively-maintained neuronal representation or trace of relevant target information (Näätänen, 1982, 1988; Schröger et al., 2015). Maintaining a trace is effortful, although it is thought to facilitate the processing of the relevant stimulus input (Näätänen, 1982). In view of that, PN may be considered as a putative marker of proactive information processing, which could provide useful insight into the cognitive strategy that individuals are using in a task.

PN is traditionally quantified in oddball tasks as a frontocentral negative difference (Nd) between target and nontarget ERP data, and may involve an early and late component (Hansen & Hillyard, 1980; Näätänen et al., 1981). The early auditory PN occurs between 50–250 ms and is hemispheric in its distribution when quantified with temporal principal components analysis (PCA: Curry et al., 1983), consistent with suggestions that the early PN is generated in sensory-specific areas (Näätänen & Picton, 1987; Vaughan & Ritter, 1970; Woods et al., 1993); note, however, that a more recent examination of Nd indicated that the early PN is generated in the frontal lobe (Picton et al., 1999).

Previous ERP/PCA research has identified an early hemispheric PN in auditory equiprobable Go/NoGo tasks at ~ 160 ms poststimulus, suggesting that participants proactively select or identify target information in that paradigm (Barry & De Blasio, 2013; Barry, De Blasio, & Cave, 2016; Borchard et al., 2015). However, recent research comparing auditory oddball and equiprobable Go/NoGo processing has questioned the identity of that component (Fogarty et al., 2019).

According to Attentional Trace Theory, PN should increase with target probability, representing sensory reinforcement of the attentional trace, as shown using Nd (Alho et al., 1990). In contrast, Fogarty et al. (2019) found that the early hemispheric PN increased as stimulus probability decreased. However, it was suggested that the hemispheric negativity identified in that task may not represent the traditional PN, but rather N1c, which had not been identified in the auditory Go/NoGo paradigm. Accordingly, the presence of PN in that task is also unclear; this

has important implications for auditory Go/NoGo processing, as the absence of the PN could indicate that young adults are not proactively processing target stimuli in that task.

The purpose of this study was to clarify the early information and control processing associated with auditory Go/NoGo tasks. To do so, this study first aimed to identify the traditional PN (Nd) in healthy young adults who completed both an 'equiprobable' and 'frequent Go' variant of the auditory Go/NoGo task. The difference between these tasks was in the probability of Go stimuli, which was expected to facilitate the characterisation of the hemispheric negativity and the identification of PN.

To gain further insight into early Go/NoGo processing, this study also aimed to explore the active neuronal sources, and stimulus type and probability effects associated with the series of temporal PCA-derived ERP components in the first 250 ms of task processing; that is, P1, N1, P2, and N2b. This was expected to provide a more detailed account of the sequential processing of auditory information in the Go/NoGo task, and of the discrete ERP/PCA components that are commonly used to study information and control processing in two-choice tasks.

Healthy young adults were expected to show a traditional PN, marked by an Nd in the 50-250 ms poststimulus period in the Go/NoGo ERP difference waveforms, indicating that young adults were proactively processing target information. Nd was hypothesised to increase with Go probability, consistent with Alho et al. (1990) and the theories relating PN to selective attention (Näätänen, 1982, 1988; Schröger et al., 2015). The PCA-derived hemispheric negativity identified in Fogarty et al. (2019) was hypothesised to match N1c, a temporal negativity that is maximal over the right hemisphere, corresponding to the second negative peak in the T-complex (Woods, 1995). N1c amplitudes have been shown to decrease in predictable conditions (Timm et al., 2013); thus, the hemispheric negativity was also expected to decrease as stimulus probability increased, supporting its identification as N1c, and its distinction from PN. No additional hypotheses were made regarding the other components (or analyses) included in this study.

2. Method

2.1. Participant demographics and screening

Sixty healthy young adult university students volunteered for this study in return for course credit (31 female; $M = 20.4$, $SD = 3.1$ years), through the University of Wollongong School of Psychology Research Participation Scheme. Before testing, each participant gave their informed consent and was assessed against key exclusion criteria: those with ongoing mental health issues, pre-existing central neurological complaints, or head injuries causing unconsciousness, were excluded, along with those who had consumed psychoactive substances ($\leq$ 12 hours), or caffeine/tobacco ($\leq$ 4 hours) before testing. Participants were also required to be right-handed, which was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971).

This research was completed in accordance with a protocol approved by the University of Wollongong and Illawarra Shoalhaven Local Health District Human Research Ethics Committee.

2.2. Physiological recording

Continuous electrophysiological data, from DC to 30 Hz, were recorded throughout each task using a Neuroscan Synamps2 amplifier (sampling rate: 1000 Hz). EEG data were recorded from 30 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2) and the right mastoid, grounded at AFz and referenced to the left mastoid. EOG data were also recorded with four electrodes placed beside the outer canthi, and above and below the left eye. Non-polarisable sintered Ag/AgCl electrodes were used for cap and EOG electrodes, with impedances below 5 kΩ.

2.3. Task and procedure

Participants were first seated in a darkened sound-attenuated room to complete a brief EOG calibration task (Croft & Barry, 2000). Afterwards, participants received equipment and instructions for two auditory Go/NoGo tasks, each involving two blocks of 150 uncued Go/NoGo tones (1000 or 1500 Hz). Tones were presented through circumaural headphones at 60 dB SPL (calibrated by an artificial ear and sound level meter: Brüel & Kjær, model 4152), using a stimulus-onset asynchrony (SOA) of 1250 ms. The duration of each tone was 80 ms, including 15 ms rise/fall times. The tone (i.e., trial) order was shuffled prior to each block, and the Go and NoGo tone frequencies were counterbalanced across blocks, within each task. The only difference between these two tasks was the global stimulus probability: in one task, Go and NoGo tones were *equiprobable* (p[Go] = .5); in the other, Go tones were more *frequent* (p[Go] = .7). Task and block order were counterbalanced across participants.

Participants were instructed to respond to the Go tone as quickly and accurately as possible, whilst ignoring the other (NoGo) tone. All responses had to be made with a button-press with the right thumb, using a Logitech® Precision Gamepad Controller. An example of the Go tone, and a short practice, was provided before each block. Ten random trials were presented in each practice, with the same Go tone and stimulus probability as the subsequent block; practice blocks were repeated if necessary.

2.4. Measure quantification

2.4.1. Behavioural performance

Individual mean response time (RT) was calculated across Go trials in each task. RTs exceeding 2 *SD* above or below the mean RT were classified as Slow or Fast RT errors, reflecting unusually delayed or impulsive responses, respectively. Mean RT and intra-individual standard deviation of RT (ISD) were recalculated after erroneous or artefactual trials were rejected (see Method 2.4.2), to ensure that these measures reflected only correct/accepted Go trials. Go omission and NoGo commission error rates were also recorded to assess Go and NoGo accuracy.

2.4.2. ERPs

After EOG-correcting the raw EEG data using the regression approach established by Croft and Barry (2000), the data were re-referenced to digitally linked mastoids, and lowpass filtered to 25 Hz (FIR, 24 dB/Octave, zero phase shift) in Neuroscan (Compumedics, v. 4.5). Go and NoGo trials were first separated into full epochs ranging from -100 to +750 ms relative to stimulus onset, and then baselined using their prestimulus period. Any epochs containing incorrect responses, or artefact exceeding ± 100 μV at any electrode, were rejected. The remaining trials were then averaged across blocks to form Go and NoGo ERPs for each participant in each task, resulting in four ERP datasets separated by stimulus type (i.e., Go vs. NoGo) and stimulus probability (i.e., Higher vs. Lower): equiprobable Go (G50), equiprobable NoGo (N50), frequent Go (G70), and rare NoGo (N30). Difference waveforms were then computed within subjects by subtracting the averaged NoGo ERP data from the mean Go data within each task; these waveforms were then examined for Nd.

Following Barry, De Blasio, Fogarty, and Karamacoska (2016), separate temporal PCAs were conducted on a restricted 0–250 ms period of each ERP dataset in Matlab (The Mathworks, v. 8.0, R2012b), to enhance the extraction of the early auditory ERP components. This process was implemented using the erpPCA functions provided by Kayser and Tenke (2003: http://bit.ly/2oX0etA), adjusted to omit the subtraction of the grand mean (GM) ERP (Dien & Frishkoff, 2005). Each PCA was implemented using the covariance matrix with Kaiser normalisation, and unrestricted Varimax rotation, and included 1800 cases (60 participants × 30 sites) and 250 variables (timepoints). PCA factors explaining ≥ 5 % of the ERP variance were output in variance order (largest to smallest), and were manually identified as ERP components according to their topography and latency; this process was guided by the preceding ERP literature (as outlined in the Introduction). If an expected component (i.e., P1, N1, P2, or N2) was not extracted in a condition at first, it was searched for below the variance cut-off (down to ≥ 2 %) if it met the initial threshold in another condition.

2.5. Statistical analysis

Behavioural performance outcomes were compared between tasks using paired sample *t*-tests. Following Barry, De Blasio, Fogarty, and Karamacoska (2016), matching components were compared to determine whether the same (or similar) components were extracted within each dataset. Tucker's (1951) congruence coefficients (r_c) were calculated between the unscaled factor loadings of matching components to assess their temporal similarity; components are considered temporally equivalent if $r_c \geq 0.95$, and highly similar when $0.85 \leq r_c \leq 0.94$ (Lorenzo-Seva & ten Berge, 2006). Simple correlations were also calculated between component amplitudes (at each of the 30 sites) to assess their topographic similarity. GM components were then formed for further analyses by averaging matching PCA component waveforms.

2.5.1. Stimulus type and probability

Two-way repeated measures ANOVAs were used to analyse stimulus type (Go vs. NoGo) and stimulus probability (Higher vs. Lower) effects on the peak component amplitudes in each dataset. Individual peak component amplitudes were computed within each dataset as an average across the electrodes marking the component's key topographical features, based on the peak electrode sites and contour lines in the GM component headmaps. This approach helped to minimise the influence of any random error that could be attributed to a single site (Barry & De Blasio, 2015). Each *F*-test had (1, 59) degrees of freedom with statistical significance determined at $\alpha < .05$.

2.5.2. Source analyses

Following the methods in Barry et al. (2020), the "exact" version of low-resolution electromagnetic tomography (eLORETA: Pascual-Marqui, 2007, 2009) was used to estimate the cortical sources of the GM PCA component waveforms. This process was conducted in LORETA–KEY (v. 20170220) using default settings, with no regularisation, and a threshold of 0.0000001; and exported positive and negative data. This program separates the brain into 6,239 voxels of 5 mm^3, and outputs 3-D inverse solution locations in relation to a realistic brain atlas from the Montreal Neurological Institute (MNI); solutions are reported in voxel values in $\mu A/mm^2$. The exported voxel values were grouped according to their structural brain location and then summed to determine the most active sources that accounted for ≥ 50 % of the total current density for each component. The BAs that accounted for ≥ 90 % of the activation in those structures were also reported.

3. Results

3.1. Trial and behavioural outcomes

There was no significant difference between the mean percentage of Go trials accepted in the equiprobable (*M* = 93.2, *SD* = 4.3 %) and frequent Go conditions (*M* = 93.3, *SD* = 3.3 %) after error and artefact rejection; *t*[59] = -0.08, *p* = .936. On average, a larger proportion of NoGo trials were accepted in the equiprobable (*M* = 95.0, *SD* = 4.2 %) compared to the rare NoGo condition (*M* = 90.5, *SD* = 7.2 %); *t*[59] = 6.36, *p* < .001. The behavioural performance outcomes are summarised in Table 1. Mean Go RTs were significantly shorter in the frequent Go condition; *t*(59) = 4.32, *p* < .001. The G70/N30 task was also associated with higher rates of NoGo commission errors (*t*[59] = -7.65, *p* < .001), and Fast RT errors (*t*[59] = -1.82, *p* = .036).

Table 1

GM (and SD) for the Behavioural Outcomes by Task

	Error Rates (%)				Go Response Time (ms)	
	Commissions**	Omissions	Fast RTs*	Slow RTs	Mean**	ISD
G50/N50	3.46 (2.71)	1.62 (2.98)	0.23 (0.42)	3.98 (1.06)	364.49 (50.50)	75.87 (24.18)
G70/N30	8.62 (6.92)	1.31 (2.07)	0.38 (0.47)	3.94 (1.10)	345.00 (58.53)	74.24 (30.81)

N.B. ISD = intra-individual standard deviation; *significant at *p* < .05; **significant at *p* < .001

3.2. Raw ERP outcomes

Figure 1 depicts the GM raw ERPs in each condition. At each level of stimulus probability, Go/NoGo stimulus onset is followed by a minor positive-going P1 wave that peaks ~ 60 ms poststimulus. P1 is followed by a major N1, involving a dominant frontocentral N1b at ~ 120 ms, and a T-complex represented by the negative "double-peak" between 80 and 160 ms at the temporal scalp sites (see T7 and T8 in Figure 1); the two negative peaks in the T-complex are considered to reflect N1a and N1c, respectively. Go P2 was evident ~ 190 ms poststimulus, followed by N2c, P3b and a target Slow Wave (SW); whereas NoGo N2b peaked at ~ 220 ms poststimulus, and was succeeded by P3a, and a nontarget SW. No evidence of Nd was found in the Go/NoGo difference waves computed for each task (see Chapter 3 Supplementary Material, pp. 65–67). Hence, the subsequent analyses focused solely on the ERP components derived using temporal PCAs.

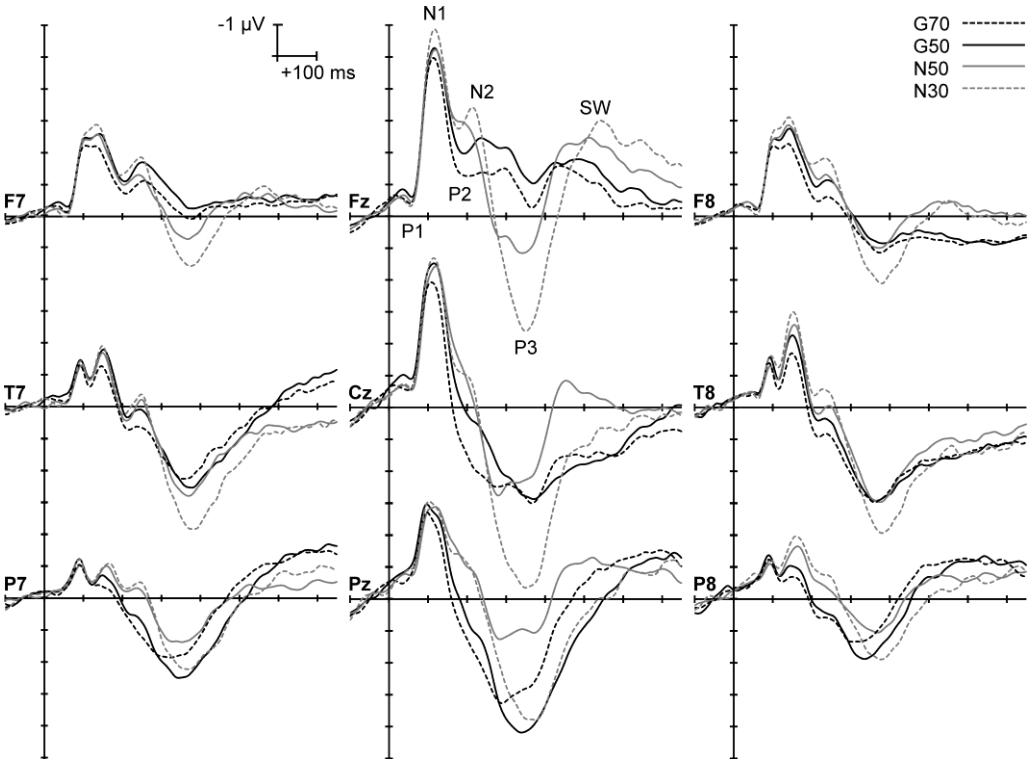
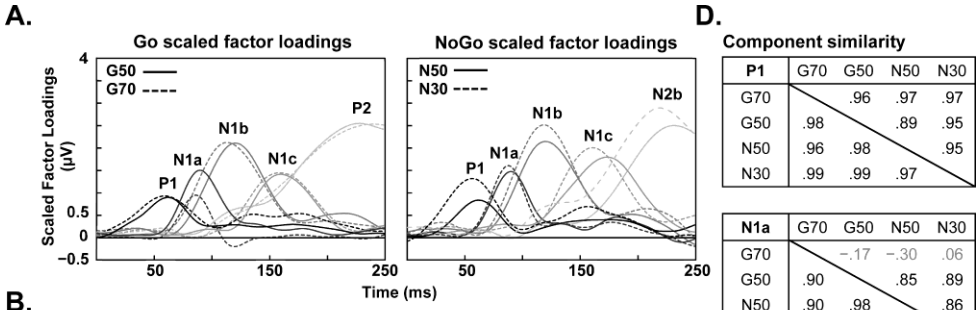


Figure 1. GM Go/NoGo ERPs in each condition at nine distinctive scalp sites; scalp locations are labelled in bolded text adjacent to each plot, and major ERP components are marked at Fz.

3.3. PCA outcomes

The PCA components identified in this study are depicted in Fig. 2. Five components were identified in each condition, including P1, N1a, N1b, and the hemispheric negativity, tentatively labelled N1c; P2 and N2b were also identified in the Go and NoGo conditions, respectively. Together, the five identified components accounted for ≥ 88.6 % of the ERP variance within each condition. However, as indicated in Fig. 2C, three components were identified below threshold, including P1 (Factor 5) in G50 and N50, and N1a (Factor 6) in G70. The statistics in Fig. 2D, above the diagonal, show that the peak topography of each component was highly similar

across conditions (r[28] ≥ .81, p < .001), excluding G70 N1a, which did not correlate with its counterparts. The congruence coefficients, below the diagonal, show that the temporal morphology of each component (including G70 N1a) was highly similar or equivalent across conditions (r_c[248] ≥ .90, p < .001).



D. Component similarity

P1	G70	G50	N50	N30
G70		.96	.97	.97
G50	.98		.89	.95
N50	.96	.98		.95
N30	.99	.99	.97	

N1a	G70	G50	N50	N30
G70		−.17	−.30	.06
G50	.90		.85	.89
N50	.90	.98		.86
N30	.94	.98	.99	

N1b	G70	G50	N50	N30
G70		.99	.99	.99
G50	.97		.99	1.0
N50	.97	.99		1.0
N30	.98	.99	.99	

N1c	G70	G50	N50	N30
G70		1.0	.82	.97
G50	.98		.81	.97
N50	.96	.96		.86
N30	.99	.99	.97	

P2/N2b	G70	G50	N50	N30
G70		.98		
G50	.99			
N50				.95
N30			.97	

Key	r
	r_c

C. Component peak latencies (ms)

	P1	N1a	N1b	N1c	P2/N2b
G70	59	86	113	159	239
G50	62	90	120	159	228
N50	62	90	120	173	231
N30	56	88	118	160	219

Unique variance (%)

	P1	N1a	N1b	N1c	P2/N2b
G70	6.6	2.2	24.5	11.7	47.9
G50	3.9	7.7	22.6	9.7	47.6
N50	3.8	7.6	24.0	19.3	35.3
N30	6.6	5.4	22.7	14.9	39.0

Figure 2. The scaled factor loadings (A), peak topography (B), peak latency and variance (C) for each PCA component identified in this study. The similarity of the components matched between conditions is summarised on the right (D), with topographical correlations (r) and congruence coefficients (r_c) above and below the diagonal, respectively; correlation coefficients in grey text were not statistically significant (i.e., p > .10).

3.4. Verification of the N1 components

Figure 3 provides a comparison of the GM raw and PCA-derived N1 components at three electrode sites distinguishing the major frontocentral N1 wave (FCz), and the T-complex (T7 and T8). As expected, the PCA-derived hemispheric negativity (i.e., N1c, represented by dashed lines in Part B) was larger over the right hemisphere, and corresponded with the second negative peak in the T-complex. The GM PCA-derived N1a and N1b also paralleled the N1a and N1b in the raw ERP data, supporting the identification of those N1 components.

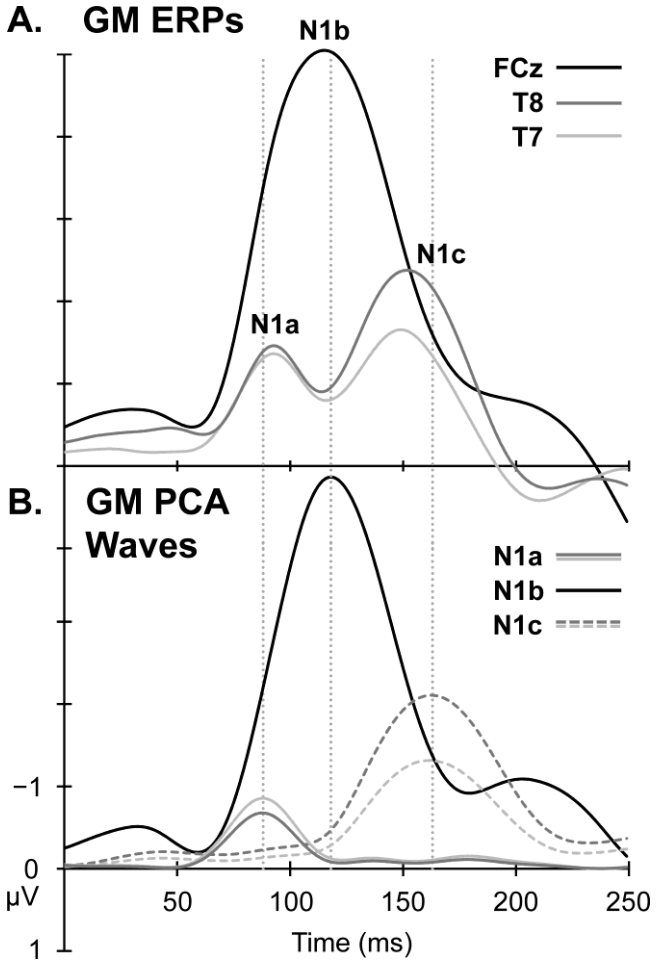


Figure 3. The GM raw ERPs (Part A) and PCA-derived N1 waveforms (Part B) over the 0-250 ms poststimulus period. The major N1b was represented using data at FCz (Black). The T-complex, including N1a and N1c, was distinguished at left and right temporal electrode sites; T8 (Dark Grey) and T7 (Light Grey), respectively.

3.5. Neuronal sources

Figure 4 shows the GM peak topography and neuronal sources associated with the P1 and N1 components identified in this study. The neuronal sources of P1 were located primarily in the frontal and parietal lobes, as well as sub-lobar regions, and the temporal, occipital, and limbic lobes. In order of descending intensity, P1 sources were active in the precuneus, cingulate gyrus, inferior frontal gyrus, superior temporal gyrus, middle frontal gyrus, postcentral gyrus, medial frontal gyrus, and insula, collectively accounting for 54.3 % of the voxel data variance. The most active BAs, explaining 90.8 % of the P1 activation in those structures, included (in descending order) BA 7, 13 (not visible in Fig. 4), 31, 6, 10, 47, 24, 11, 9, 3, 45, 23, 8, and 2.

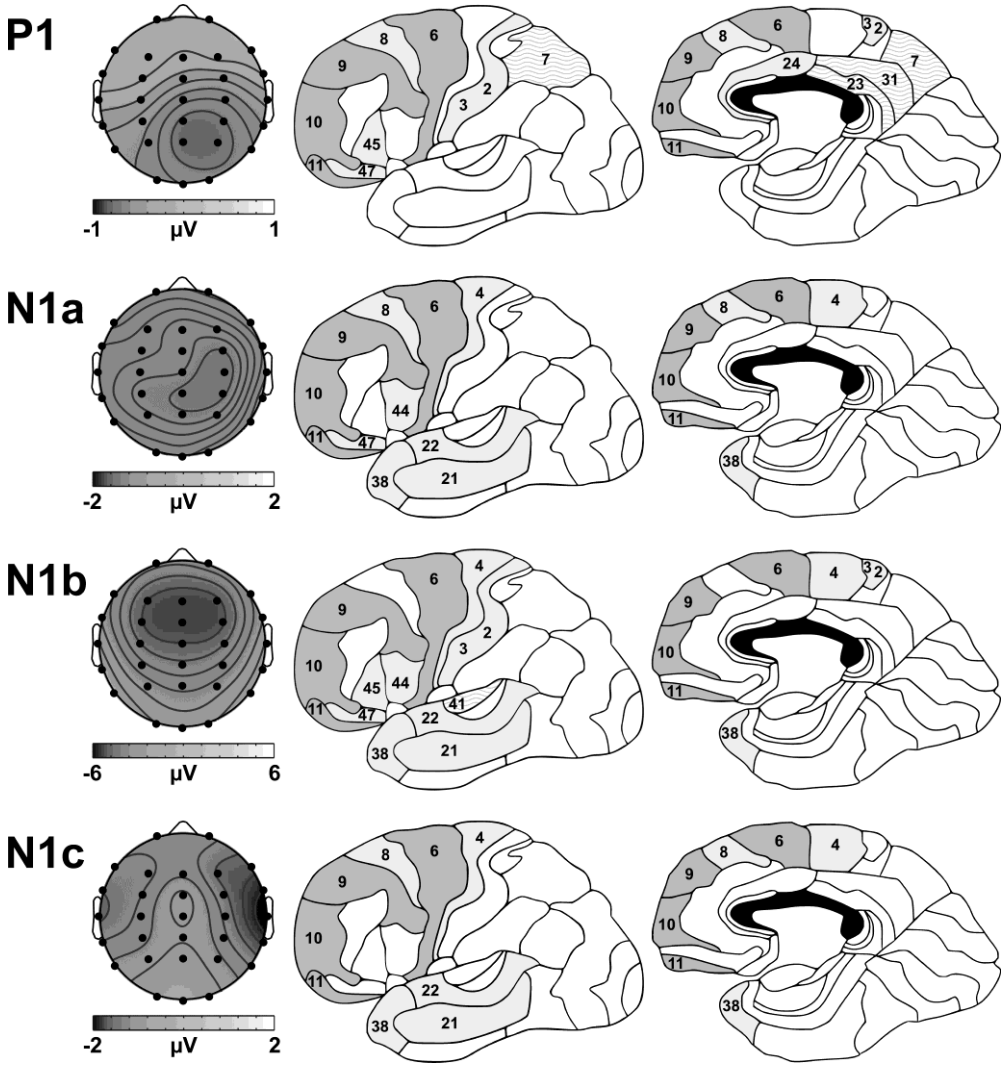


Figure 4. GM peak topography and Brodmann Areas (BAs) associated with the P1 and N1 components. Dark grey BAs were active in each component; light grey areas were active in multiple components; wavy areas were uniquely active in that component.

N1a sources were located predominantly within the frontal and temporal lobes, but were also evident in the parietal and occipital lobes. In descending order, the most active N1a sources were in the superior temporal gyrus, middle frontal gyrus, superior frontal gyrus, medial frontal gyrus, middle temporal gyrus, precentral gyrus, and inferior frontal gyrus, together explaining 54.8 % of the total voxel variance. In intensity order, the BAs accounting for 90.2 % of the N1a activation in those structures included BA 6, 21, 10, 38, 47, 22, 9, 11, 4, 8, and 44.

N1b sources were identified primarily in the frontal and temporal lobes, as well as sub-lobar areas, and the parietal, and occipital lobes. Beginning with the most active structures, N1b sources were located in the superior temporal gyrus, insula, inferior frontal gyrus, precentral gyrus, postcentral gyrus, middle temporal gyrus, and middle frontal gyrus, collectively accounting for 51.7 % of the variance. The most active BAs, explaining 90.0 % of the N1b activation in those structures, included (in descending order) BA 13, 38, 47, 21, 6, 22, 4, 3, 2, 44, 9, 11, 45, 10, and 41.

N1c sources were located predominantly within the frontal and temporal lobes, but also in the occipital and parietal lobes. The most active N1c sources (in descending order) were in the middle frontal gyrus, superior temporal gyrus, precentral gyrus, superior frontal gyrus, middle temporal gyrus, and medial frontal gyrus, explaining 51.5 % of the variance in N1c voxel data. The BAs contributing to 90.8 % of the N1c activation in those locations were, in intensity order, BA 6, 21, 8, 22, 10, 9, 11, 38, and 4.

Figure 5 illustrates the GM peak topography and neuronal sources related to Go P2 and NoGo N2b in this study. The neuronal sources of the Go P2 were primarily in the frontal, temporal, and limbic lobes, with the most active structures including (in descending order) the superior frontal gyrus, medial frontal gyrus, inferior frontal gyrus, superior temporal gyrus, middle frontal gyrus, and cingulate gyrus, together explaining 53.1 % of the variance. The most active BAs accounting for 92.3 % of the P2 activation in those structures were, in intensity order, BA 6, 8, 9, 47, 38, 10, 32, 24, 11, 22, and 45.

N2b sources were located mainly within the frontal and temporal lobes, with the most active structures (ordered by amplitude) including the superior frontal gyrus, inferior frontal gyrus, superior temporal gyrus, medial frontal gyrus, and middle frontal gyrus, collectively explaining 51.7 % of the voxel data variance. The most active BAs accounting for 93.2 % of the N2b activation in those structures included, in order of their contribution, BA 6, 47, 8, 38, 9, 10, 11, 22, and 45.

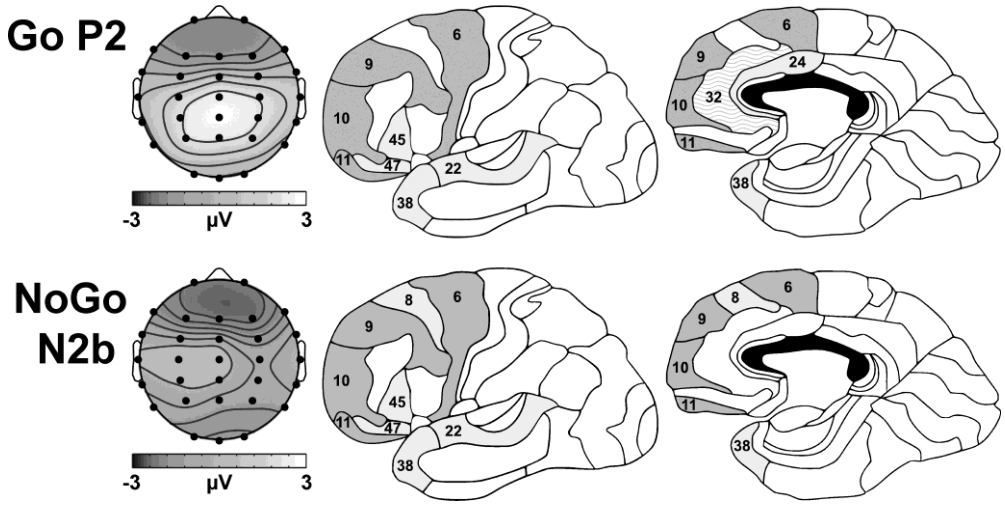


Figure 5. GM peak topography and Brodmann Areas (BAs) associated with the Go P2 and NoGo N2b. Dark grey BAs were active in each component; light grey areas were active in multiple components; wavy areas were uniquely active in that component.

3.6. Stimulus type and probability effects

The GM component amplitudes in each condition are summarised in Table 2. The repeated measures ANOVAs showed a main effect of stimulus type was found on P1, $F(1,59) = 6.48$, $p = .014$, $\eta_p^2 = .10$, with larger amplitudes following NoGo stimuli ($M = .24$, $SD = .84$ μV), relative to Go ($M = .04$, $SD = .70$ μV). N1a varied significantly with stimulus probability, $F(1,59)$

= 11.80, p = .001, η_p^2 = .17, with larger N1a amplitudes associated with lower stimulus probability (M = -1.4, SD = 1.8 μV), compared to higher probability (M = -.9, SD = 1.4 μV). That probability effect was larger for Go, than NoGo N1a amplitudes, with a significant interaction effect, F(1, 59) = 10.14, p = .002, η_p^2 = .15. NoGo N1b was significantly larger (M = -4.6, SD = 2.2 μV), than Go N1b (M = -4.2, SD = 2.0 μV), F(1, 59) = 8.33, p = .005, η_p^2 = .12; this effect was greater when stimulus probability was lower, apparent in a significant interaction, F(1, 59) = 8.36, p = .005, η_p^2 = .12. A main effect of stimulus probability was found on N1c, F(1, 59) = 15.43, p < .001, η_p^2 = .21, with larger amplitudes associated with lower stimulus probability (M = -1.9, SD = 1.1 μV), compared to higher probability (M = -1.5, SD = 1.0 μV). Go P2 amplitudes were significantly larger when Go probability was higher (M = 2.8, SD = 2.9 μV), than when Go probability was lower (M = 2.1, SD = 3.1 μV); F(1, 59) = 8.63, p = .005, η_p^2 = .13. No significant effects were found for the NoGo N2b.

Table 2

GM Component Amplitudes (and SD) by Stimulus Type and Probability

	Go		NoGo	
Probability	Higher	Lower	Higher	Lower
P1	0.15 (0.66)	-0.07 (0.72)	0.20 (0.63)	0.27 (1.00)
N1a	-0.61 (1.02)	-1.50 (1.74)	-1.22 (1.63)	-1.25 (1.83)
N1b	-4.36 (2.15)	-4.12 (1.90)	-4.26 (1.93)	-4.94 (2.35)
N1c	-1.48 (0.82)	-1.77 (0.92)	-1.58 (0.22)	-1.95 (1.22)
P2	2.83 (2.89)	2.10 (3.12)		
N2b			-1.51 (2.38)	-1.72 (2.96)

N.B. GM component amplitudes are in μV. P2 and N2b were Go and NoGo specific, respectively.

4. Discussion

This study analysed the first 250 ms of ERP data in two Go/NoGo tasks, to clarify early auditory Go/NoGo processing, and the presence of an early Go/NoGo PN in healthy young adults. No early frontal Nd was identified, and the hemispheric negativity identified in previous PCA studies matched N1c, demonstrating that there was no PN evident in young adults completing either equiprobable or frequent Go variants of the auditory Go/NoGo paradigm. Further analyses revealed complex neuronal source activations and stimulus effects throughout the Go/NoGo processing sequence, perhaps providing some direction for future models of auditory information processing.

In this study, the early PN (Nd) was expected to be evident in the Go/NoGo ERP difference waveforms between 50–250 ms poststimulus if participants were proactively processing target stimuli. No PN was identified during that period, although a frontal negativity was evident ~ 300 ms poststimulus, representing the difference between NoGo P3a and Go P3b (see Chapter 3 Supplementary Material, pp. 65–67). NoGo P3a increases with decreasing NoGo probability (Squires et al., 1975), which begs the question as to whether this P3 difference

explains the traditional findings showing Nd to increase with Go probability (Alho et al., 1990). This highlights the difficulty of interpreting ERP outcomes determined using difference waves. Despite that, the absence of Nd in this study shows that the traditional PN was not evident in young adults completing the auditory Go/NoGo task.

As hypothesised, the PCA-derived hemispheric negativity was a close representation of N1c; a temporal negativity that is larger over the right hemisphere, corresponding with the second negative peak in the T-complex (Bender et al., 2006; Woods, 1995). The hemispheric negativity also decreased in amplitude as stimulus probability increased, replicating the findings in Fogarty et al. (2019). This also follows previous research linking smaller N1c amplitudes to more predictable stimuli (Timm et al., 2013), providing further confirmation that the hemispheric negativity represents N1c, rather than PN. Together, with the absence of Nd, this suggests that young adults were not proactively (or selectively) processing target stimuli in either Go/NoGo variant.

This study replicated the ERP components associated with early auditory processing in a range of cognitive tasks (i.e., P1, N1, P2, and N2). Using PCA to decompose the early sensory period also enabled the clear separation of the true N1 components; including N1a, N1b, and N1c (Bender et al., 2006; Knight et al., 1988; McCallum & Curry, 1980; Näätänen & Picton, 1987; Nielsen-Bohlman et al., 1991; Wolpaw & Penry, 1975; Woods, 1995). Accordingly, successful auditory processing in this task was linked to a frontal P1, a small centroparietal N1a, large frontocentral N1b, and a temporal N1c. Distinctive Go and NoGo processing was evident after N1c, marked by the subsequent Go P2 and NoGo N2b (Borchard et al., 2015).

A range of neuronal sources were linked with the Go/NoGo processing series in this study, including several frontal sources that were common to P1, N1a, N1b, N1c, Go P2 and NoGo N2b (i.e., BAs 6, 8, 9, 10, and 11). This may be consistent with a parallel distributed processing framework (Cohen et al., 1990), and suggests that Go/NoGo processing involves a core frontal network that is active throughout the first 250 ms, together with additional sources specific to each component/processing stage. That core network may represent the cognitive control functions required throughout the task, perhaps including the coordination and integration of discrete cognitive operations, the maintenance of task goals in working memory, and behavioural regulation (Casey et al., 1997; Fuster, 1997; Miller & Cohen, 2001; Ramnani & Owen, 2004).

P1 was related to activity in frontal and parietal lobes, as well as sub-lobar regions, and temporal, occipital, and limbic lobes; corroborating (and extending) previous findings linking P1 to activation in frontal and temporal areas of the brain (Grunwald et al., 2003; Korzyukov et al., 2007). The parietal and sub-lobar activation in BAs 7, 23, and 31 were unique to P1, perhaps signifying an early shift in attentional focus (Leech & Sharp, 2014). Together with the involvement of the core frontal network, these outcomes support the link between P1 and auditory

sensory gating (Alho et al., 1994; Freedman et al., 1987; Knight et al., 1989; Lijffijt et al., 2009). P1 was also larger to NoGo, illustrating early stimulus-specific processing, perhaps consistent with that interpretation; however, this finding should be viewed with caution due to the small mean P1 peak amplitudes, particularly in G50 (see Table 2).

N1a activity was localised mainly in the frontal and temporal lobes, but also in some parietal and occipital areas (Näätänen & Picton, 1987). Unlike P1, no BAs were unique to N1a, relative to the other components. However, notably the frontal BAs 8 and 47 were active in relation to N1a and the preceding P1, reflecting early sequential processing in areas related to working memory (Babiloni et al., 2005; Ranganath et al., 2003), and behavioural control (Kübler et al., 2006; Sarazin et al., 1998). N1a also represented the initial activation of several regions that were common to later processing stages (i.e., BAs 4, 21, 22, 38, and 44); these BAs have been related to a range of functions, including (but certainly not limited to) auditory processing (Jäncke et al., 2002), and motor control (Grefkes et al., 2008; van der Kallen et al., 1996).

N1b was associated with activation in several structures common to P1 (BAs 2, 3, 13, and 45), and the immediately preceding N1a (BAs 4, 21, 22, 38, 44, and 47), representing the continuation of stimulus (and likely, response) processing in those areas. N1b was uniquely related to activation in BA 41, consistent with its connection to basic auditory processing, and the more general observation that N1 is generated within the primary auditory cortex (Näätänen & Picton, 1987). It is remarkable that the primary auditory cortex was not active earlier (or later) in the auditory Go/NoGo processing sequence; perhaps this suggests that auditory N1b is the primary marker of tone frequency discrimination (Liebenthal et al., 2003), or the processing of stimulus offset (Mirz et al., 1999; Näätänen, 1988).

N1c was linked to activation in frontal and temporal areas common to both P1 and N1a (BA 8), and the previous N1b (BAs 4, 21, 22, and 38). This is consistent with suggestions that N1a, N1b, and N1c reflect processing in similar cortical areas (Näätänen & Picton, 1987); indeed, BAs 4, 21, 22, and 38 were common to all three N1 components. More notably, however, is that of those cortical areas, activations in the primary motor cortex (BA 4) and the middle temporal gyrus (BA 21) were exclusive to the N1 components in this study. Together, with the frontal N1 source activations confirmed in this study, these outcomes support earlier research that proposed links between N1 and response processing in choice/RT tasks (Bender et al., 2006; Filipović et al., 2000; Kirmizi-Alsan et al., 2006).

Both N1a and N1c were larger when stimuli were rare; whereas, N1b was larger following NoGo stimuli, similar to P1. The common N1 sources and the interaction effects noted in the results could signify some functional overlap or crosstalk between these components, however, the main effects identified here could help distinguish the functional specificity of N1b and the T-complex; comprising N1a and N1c. Namely, that N1b is sensitive to stimulus type (or

significance), while the T-complex is related to stimulus probability (or predictability: Schröger et al., 2015; Timm et al., 2013).

Go P2 and NoGo N2b were both active in BAs 22, 38, 45, and 47, implying some continued information processing in the frontal and temporal areas associated with P1 and N1. Additionally, P2 was also active in BA 24, and uniquely, BA 32; representing the ventral and dorsal anterior cingulate, respectively. P2 was also larger when Go probability was higher (as in Fogarty et al. 2019). Together, these outcomes corroborate the suggestion that auditory P2 is (at least) partly generated in the temporal lobe (Crowley & Colrain, 2004; Rif et al., 1991). Its link to the anterior cingulate could also substantiate its relationship with sensory gating or attention (Benedict et al., 1998; Lijffijt et al., 2009), which was perhaps enhanced by increasing the predictability of Go stimuli.

This study suggests that the temporal PN (or N1) identified in previous PCA studies was N1c. From that viewpoint, those earlier studies indicate that larger N1c amplitudes are associated with caffeine consumption (Barry, De Blasio, & Cave, 2014; Barry, De Blasio, & Fogarty, 2019), shorter oddball RTs (Steiner et al., 2016), and the processing of tonal stimuli (vs. phonetic stimuli: Kayser & Tenke, 2006). Previous studies would also suggest that N1c is more enhanced at temporal sites (relative to the midline) following Go stimuli, although that may be because the NoGo counterpart was often more negative at frontal-midline sites (Barry & De Blasio, 2013; Barry, De Blasio, & Cave, 2014; Barry, De Blasio, De Pascalis, & Karamacoska, 2014; Barry, De Blasio, & Cave, 2016; Barry et al., 2018; Borchard et al., 2015). These observations, and the present findings, strongly support a link between N1c and stimulus-response processing, at least in paradigms that require a response. Moreover, the clarification of those effects could provide useful insight for researchers using the T-complex to study auditory perception or deficits in individuals with learning difficulties (e.g., dyslexia: Hämäläinen et al., 2011, 2015; Wagner et al., 2016).

The absence of PN in this study was considered to show that young adults were not proactively processing target stimuli, following theories suggesting that PN represents activity associated with an attentional trace (Näätänen, 1982), stimulus set (Hillyard & Kutas, 1983), or prediction of target stimulus input (Schröger et al., 2015). However, that does not discount the possibility of proactive *response* processing. Indeed, Go primacy effects were identified in this study, as signified by the shorter RTs and higher commission error rates in the frequent Go (vs. equiprobable) variant of the Go/NoGo task. Hence, the present findings tentatively suggest that increasing stimulus probability can prime response processes separately from sensory processing. Alternatively, the present findings could question the traditional view of PN as a marker of early, proactive, or selective information processing.

Several limitations in this study can be addressed in future research. Firstly, this study was limited to the first 250 ms of task processing, which aided the PCA extraction of the early

ERP components that were the focus of this study; however, it would be useful to apply the same analyses to later time periods so that the present findings can be considered relative to the broader task processing sequence. Source analyses should also be conducted on the Go and NoGo P1 and N1 components separately. In this study, source analyses were conducted on GM components, preventing the detection of possible Go/NoGo source differences that might help to elucidate the early stimulus-specific effects on component amplitudes. Including a classic oddball task would also have been useful to verify the traditional PN (Nd) in the current sample, and to strengthen the conclusions in this study by providing a PN for comparative purposes.

The ERP source outcomes in this study also indicate that each component represents complex neuronal activations that could be consistent with a parallel distributed processing framework, which posits that information processing occurs as activity propagates through a system of connected modules (i.e., neuronal sources: Cohen et al., 1990). Accordingly, analysing the functional connectivity between the active areas identified in each component could potentially further our understanding of the discrete processing stages in auditory Go/NoGo tasks. That approach could also assist in the confirmation of the core network of (pre)frontal areas identified in this study, and assist in clarifying its role (and that of other brain areas) in the sequential processing of auditory information. Additional research is also important to verify this distributed model of the component sources. LORETA has lower spatial resolution due to an intrinsic Laplacian 'smoothness' constraint (He & Ding, 2013; Michel et al., 2004). Thus, while eLORETA is considered robust against noise and advantageous for deep source localisation, other techniques or algorithms may provide greater specificity; at least, relative to LORETA (see Grech et al., 2008; Halder et al., 2019; Michel et al., 2004). The liberal output and lack of *a priori* assumptions about the source distribution in this study is considered favourable for exploratory source analyses (Halder et al., 2019). Extraneous source activation was also controlled (albeit arbitrarily) by variance thresholds to highlight the most important sources; however, researchers should be mindful that these results reflect one of many possible source models for the early factors in this auditory Go/NoGo study, and until these results can be cross-checked and validated with other methods the source distributions identified in this study should be considered carefully.

This study clarified the early ERP/PCA factors related to auditory Go/NoGo sensory processing in young adults. As expected, the hemispheric negativity identified in previous ERP/PCA research was a marker of N1c. Together with the absence of the traditional PN (Nd), this suggests that young adults did not proactively process the target stimulus input in this paradigm. However, the behavioural outcomes showed that the Go response was still primed by increasing target probability; this has interesting implications for the cognitive control of both stimulus and response processing. A complex of neuronal generators was associated with each factor/processing stage in this study. In future, these observations could provide a useful basis for models of auditory information and control processing in healthy young adults.

References

Alho, K., Lavikainen, J., Reinikainen, K., Sams, M., & Näätänen, R. (1990). Event-related brain potentials in selective listening to frequent and rare stimuli. *Psychophysiology, 27*(1), 73–86. https://doi.org/10.1111/j.1469-8986.1990.tb02183.x

Alho, K., Woods, D. L., Algazi, A., Knight, R. T., & Näätänen, R. (1994). Lesions of frontal cortex diminish the auditory mismatch negativity. *Electroencephalography and Clinical Neurophysiology, 91*(5), 353–362. https://doi.org/10.1016/0013-4694(94)00173-1

Babiloni, C., Ferretti, A., Del Gratta, C., Carducci, F., Vecchio, F., Romani, G. L., & Rossini, P. M. (2005). Human cortical responses during one-bit delayed-response tasks: an fMRI study. *Brain Research Bulletin, 65*(5), 383–390. https://doi.org/10.1016/j.brainresbull.2005.01.013

Barry, R. J., & De Blasio, F. M. (2013). Sequential processing in the equiprobable auditory Go/NoGo task: A temporal PCA study. *International Journal of Psychophysiology, 89*(1), 123–127. https://doi.org/10.1016/j.ijpsycho.2013.06.012

Barry, R. J., & De Blasio, F. M. (2015). Performance and ERP components in the equiprobable go/no-go task: Inhibition in children. *Psychophysiology, 52*(9), 1228–1237. https://doi.org/10.1111/psyp.12447

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2014). Caffeine effects on ERP components and performance in an equiprobable auditory Go/NoGo task. *Journal of Caffeine Research, 4*(3), 83–92. https://doi.org/10.1089/jcr.2014.0011

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2016). Sequential processing in younger and older adults in the equiprobable auditory Go/NoGo task. *Clinical Neurophysiology, 127*(5), 2273–2285. https://doi.org/10.1016/j.clinph.2016.02.010

Barry, R. J., De Blasio, F. M., De Pascalis, V., & Karamacoska, D. (2014). Preferred EEG brain states at stimulus onset in a fixed interstimulus interval equiprobable auditory Go/NoGo task: A definitive study. *International Journal of Psychophysiology, 94*(1), 42–58. https://doi.org/10.1016/j.ijpsycho.2014.07.005

Barry, R. J., De Blasio, F. M., & Fogarty, J. S. (2019). Caffeine affects children's ERPs and performance in an equiprobable go/no-go task: Testing a processing schema. *Psychophysiology, 56,* Article e13330. https://doi.org/10.1111/psyp.13330

Barry, R. J., De Blasio, F. M., Fogarty, J. S., & Karamacoska, D. (2016). ERP Go/NoGo condition effects are better detected with separate PCAs. *International Journal of Psychophysiology, 106*, 50–64. https://doi.org/10.1016/j.ijpsycho.2016.06.003

Barry, R. J., Fogarty, J. S., De Blasio, F. M., & Karamacoska, D. (2018). EEG phase states at stimulus onset in a variable-ISI Go/NoGo task: Effects on ERP components. *Biological Psychology, 134*, 89–102. https://doi.org/10.1016/j.biopsycho.2018.02.005

Barry, R. J., Steiner, G. Z., De Blasio, F. M., Fogarty, J. S., Karamacoska, D., & MacDonald, B.

(2020). Components in the P300: Don't forget the Novelty P3!. *Psychophysiology*, Article e13371. https://doi.org/10.1111/psyp.13371

Bender, S., Oelkers-Ax, R., Resch, F., & Weisbrod, M. (2006). Frontal lobe involvement in the processing of meaningful auditory stimuli develops during childhood and adolescence. *NeuroImage*, *33*(2), 759–773. https://doi.org/10.1016/j.neuroimage.2006.07.003

Benedict, R. H. B., Lockwood, A. H., Shucard, J. L., Shucard, D. W., Wack, D., & Murphy, B. W. (1998). Functional neuroimaging of attention in the auditory modality. *NeuroReport*, *9*(1), 121–126. https://doi.org/10.1097/00001756-199801050-00024

Borchard, J. P., Barry, R. J., & De Blasio, F. M. (2015). Sequential processing in an auditory equiprobable Go/NoGo task with variable interstimulus interval. *International Journal of Psychophysiology*, *97*(2), 145–152. https://doi.org/10.1016/j.ijpsycho.2015.05.010

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, *8*(12), 539–546. https://doi.org/10.1016/j.tics.2004.10.003

Casey, B. J., Trainor, R. J., Orendi, J. L., Schubert, A. B., Nystrom, L. E., Giedd, J. N., Castellanos, F. X., Haxby, J. V., Noll, D. C., Cohen, J. D., Forman, S. D., Dahl, R. E., & Rapoport, J. L. (1997). A developmental functional MRI study of prefrontal activation during performance of a go-nogo task. *Journal of Cognitive Neuroscience*, *9*(6), 835–847. https://doi.org/10.1162/jocn.1997.9.6.835

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review*, *97*(3), 332–361. https://doi.org/10.1037/0033-295x.97.3.332

Croft, R. J., & Barry, R. J. (2000). EOG correction of blinks with saccade coefficients: A test and revision of the aligned-artefact average solution. *Clinical Neurophysiology*, *111*(3), 444–451. https://doi.org/10.1016/S1388-2457(99)00296-5

Crowley, K. E., & Colrain, I. M. (2004). A review of the evidence for P2 being an independent component process: Age, sleep and modality. *Clinical Neurophysiology*, *115*(4), 732–744. https://doi.org/10.1016/j.clinph.2003.11.021

Curry, S. H., Cooper, R., McCallum, W. C., Pocock, P. V., Papakostopoulos, D., Skidmore, S., & Newton, P. (1983). The principal components of auditory target detection In A. W. K. Gaillard & W. Ritter (Eds.), *Tutorials in ERP research: Endogenous components* (pp. 79–117). North-Holland Publishing Company.

Dien, J., & Frishkoff, G. A. (2005). Introduction to principal components analysis of event-related potentials. In T. Handy (Ed.), *Event-related potentials: A methods handbook* (pp. 189–208). Cambridge, MA: MIT Press.

Dien, J., Tucker, D. M., Potts, G., & Hartry-Speiser, A. (1997). Localization of auditory evoked potentials related to selective intermodal attention. *Journal of Cognitive Neuroscience,*

9(6), 799–823. https://doi.org/10.1162/jocn.1997.9.6.799

Filipović, S. R., Jahanshahi, M., & Rothwell, J. C. (2000). Cortical potentials related to the nogo decision. *Experimental Brain Research, 132*(3), 411–415.

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2019). Sequential processing in the classic oddball task: ERP components, probability, and behavior. *Psychophysiology, 56*(3), Article e13300. https://doi.org/10.1111/psyp.13300

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology, 45*(1), 152–170. https://doi.org/10.1111/j.1469-8986.2007.00602.x

Freedman, R., Adler, L. E., Gerhardt, G. A., Waldo, M., Baker, N., Rose, G. M., Drebing, C., Nagamoto, H., Bickford-Wimer, P., & Franks, R. (1987). Neurobiological studies of sensory gating in schizophrenia. *Schizophrenia Bulletin, 97*(4), 669–678. https://doi.org/10.1093/schbul/13.4.669

Fuster, J. M. (1997). *The prefrontal cortex: anatomy, physiology, and neuropsychology of the frontal lobe*. Raven Press.

Giard, M. H., Perrin, F., Echallier, J. F., Thévenet, M., Froment, J. C., & Pernier, J. (1994). Dissociation of temporal and frontal components in the human auditory N1 wave: A scalp current density and dipole model analysis. *Electroencephalography and Clinical Neurophysiology, 92*(3), 238–252. https://doi.org/10.1016/0168-5597(94)90067-1

Gomez, P., Ratcliff, R., & Perea, M. (2007). A model of the go/no go task. *Journal of Experimental Psychology, 136*(3), 389–413. https://doi.org/10.1037/0096-3445.136.3.389.A

Gratton, G., Cooper, P., Fabiani, M., Carter, C. S., & Karayanidis, F. (2018). Dynamics of cognitive control: Theoretical bases, paradigms, and a view for the future. *Psychophysiology, 55*(3), 1–29. https://doi.org/10.1111/psyp.13016

Grau, C., Fuentemilla, L., & Marco-Pallarés, J. (2007). Functional neural dynamics underlying auditory event-related N1 and N1 suppression response. *NeuroImage, 36*(3), 522–531. https://doi.org/10.1016/j.neuroimage.2007.03.027

Grech, R., Cassar, T., Muscat, J., Camilleri, K. P., Fabri, S. G., Zervakis, M., Xanthopoulos, P., Sakkalis, V., & Vanrumste, B. (2008). Review on solving the inverse problem in EEG source analysis. *Journal of Neuroengineering and Rehabilitation*, *5*(1), Article 25. https://doi.org/10.1186/1743-0003-5-25

Grefkes, C., Eickhoff, S. B., Nowak, D. A., Dafotakis, M., & Fink, G. R. (2008). Dynamic intra- and interhemispheric interactions during ipsilateral and bilateral hand movements assessed with fMRI and DCM. *NeuroImage, 41*(4), 1382–1394. https://doi.org/10.1016/j.neuroimage.2008.03.048

Grunwald, T., Boutros, N. N., Pezer, N. von Oertzen, J., Fernández, G., Schaller, C., & Elger, C.

E. (2003). Neuronal substrates of sensory gating within the human brain. *Biological Psychiatry*, *53*(6), 511–519. https://doi.org/10.1016/s0006-3223(02)01673-6

Halder, T., Talwar, S., Jaiswal, A. K., & Banerjee, A. (2019). Quantitative evaluation in estimating sources underlying brain oscillations using current source density methods and beamformer approaches. *Eneuro*, *6*(4), 1–14. https://doi.org/10.1523/ENEURO.0170-19.2019

Hämäläinen, J. A., Fosker, T., Szücs, D., & Goswami, U. (2011). N1, P2 and T-complex of the auditory brain event-related potentials to tones with varying rise times in adults with and without dyslexia. *International Journal of Psychophysiology*, *81*(1), 51–59. https://doi.org/10.1016/j.ijpsycho.2011.04.005

Hämäläinen, J. A., Lohvansuu, K., Ervast, L., & Leppänen, P. H. (2015). Event-related potentials to tones show differences between children with multiple risk factors for dyslexia and control children before the onset of formal reading instruction. *International Journal of Psychophysiology*, *95*(2), 101–112. https://doi.org/10.1016/j.ijpsycho.2014.04.004

Hansen, J. C., & Hillyard S. A. (1980). Endogenous brain potentials associated with selective auditory attention. *Electroencephalography and Clinical Neurophysiology*, 49(3–4): 392–398. https://doi.org/10.1016/0013-4694(80)90222-9

He, B., & Ding, L. (2013) Electrophysiological Mapping and Neuroimaging. In B. He (Ed.) *Neural Engineering* (pp. 499–543). Boston, MA: Springer. https://doi.org/10.1007/978-1-4614-5227-0_12

Hillyard, S. A., & Kutas, M. (1983). Electrophysiology of cognitive processing. *Annual Reviews of Psychology*, *34*, 33–61. https://doi.org/10.1146/annurev.ps.34.020183.000341

Jäncke, L., Wüstenberg, T., Schulze, K., & Heinze, H. J. (2002). Asymmetric hemodynamic responses of the human auditory cortex to monaural and binaural stimulation. *Hearing Research*, *170*(1–2), 166–178. https://doi.org/10.1016/s0378-5955(02)00488-4

Joos, K., Gilles, A., Van de Heyning, P., De Ridder, D., & Vanneste, S. (2014). From sensation to percept: The neural signature of auditory event-related potentials. *Neuroscience and Biobehavioral Reviews*, *42*, 148–156. https://doi.org/10.1016/j.neubiorev.2014.02.009

Kayser, J., & Tenke, C. E. (2003). Optimizing PCA methodology for ERP component identification and measurement: Theoretical rationale and empirical evaluation. *Clinical Neurophysiology*, *114*(12), 2307–2325. https://doi.org/10.1016/S1388-2457(03)00241-4

Kayser, J., & Tenke, C. E. (2006). Principal components analysis of Laplacian waveforms as a generic method for identifying ERP generator patterns: II. Adequacy of low-density estimates. *Clinical Neurophysiology*, *117*(2), 369–380. https://doi.org/10.1016/j.clinph.2005.08.033

Kirmizi-Alsan, E., Bayraktaroglu, Z., Gurvit, H., Keskin, Y. H., Emre, M., & Demiralp, T.

(2006). Comparative analysis of event-related potentials during Go/NoGo and CPT: Decomposition of electrophysiological markers of response inhibition and sustained attention. *Brain Research, 1104*(1), 114–128. https://doi.org/10.1016/j.brainres.2006.03.010

Knight, R. T., Scabini, D., & Woods, D. L. (1989). Prefrontal cortex gating of auditory transmission in humans. *Brain Research, 504*(2), 338–342. https://doi.org/10.1016/0006-8993(89)91381-4

Knight, R. T., Scabini, D., & Woods, D. L., & Clayworth, C. (1988). The effect of lesions of superior temporal gyrus and inferior parietal lobe on temporal and vertex components of the human AEP. *Electroencephalography and Clinical Neurophysiology, 70*(6), 499–509. https://doi.org/10.1016/0013-4694(88)90148-4

Korzyukov, O., Pflieger, M. E., Wagner, M., Bowyer, S. M., Rosburg, T., Sundaresan, K., Elger, C. E., & Boutros, N. N. (2007). Generators of the intracranial P50 response in auditory sensory gating. *NeuroImage, 35*(2), 814–826. https://doi.org/10.1016/j.neuroimage.2006.12.011

Kübler, A., Dixon, V., & Garavan, H. (2006). Automaticity and reestablishment of executive control-an fMRI study. *Journal of Cognitive Neuroscience, 18*(8), 1331–1342. https://doi.org/10.1162/jocn.2006.18.8.1331

Leech, R., & Sharp, D. J. (2014). The role of the posterior cingulate cortex in cognition and disease. *Brain, 137*(1), 12–32. https://doi.org/10.1093/brain/awt162

Liebenthal, E., Ellingson, M. L., Spanaki, M. V., Prieto, T. E., Ropella, K. M., & Binder, J. R. (2003). Simultaneous ERP and fMRI of the auditory cortex in a passive oddball paradigm. *NeuroImage, 19*(4), 1395–1404. https://doi.org/10.1016/s1053-8119(03)00228-3

Lijffijt, M., Lane, S. D., Meier, S. L., Boutros, N. N., Burroughs, S., Steinberg, J. L., Moeller, F. G., & Swann, A. C. (2009). P50, N100, and P200 sensory gating: Relationships with behavioral inhibition, attention, and working memory. *Psychophysiology, 46*(5), 1059–1068. https://doi.org/10.1111/j.1469-8986.2009.00845.x

Lorenzo-Seva, U., & ten Berge, J. M. F. (2006). Tucker's congruence coefficient as a meaningful index of factor similarity. *Methodology, 2*(2), 57–64. https://doi.org/10.1027/1614-2241.2.2.57

Lü, Z. L., Williamson, S. J., & Kaufman, L. (1992). Human auditory primary and association cortex have differing lifetimes for activation traces. *Brain Research, 572*(1–2), 236–241. https://doi.org/10.1016/0006-8993(92)90475-o

Lütkenhöner, B., & Steinsträter, O. (1998). High-precision neuromagnetic study of the functional organization of the human auditory cortex. *Audiology and Neurotology, 3*(2–3), 191–213. https://doi.org/10.1159/000013790

Martin, B. A., Tremblay, K. L., & Stapells, D. R. (2007). Principles and applications of cortical auditory evoked potentials. In R. Burkard, M. Don & J. Eggermont (Eds.), *Auditory Evoked Potentials: Basic Principles and Clinical Application* (pp. 482–507). Lippincott Williams and Wilkins.

McCallum, W. C., & Curry, S. H. (1980). The form and distribution of auditory event related potentials and CNVs when stimuli and responses are lateralized. In H. H. Kornhuber & L. Deecke (Eds.), *Motivation, motor and sensory processes of the brain: Electrical potentials, behaviour and clinical use* (pp. 767–775). Elsevier.

Michel, C. M., Murray, M. M., Lantz, G., Gonzalez, S., Spinelli, L., & de Peralta, R. G. (2004). EEG source imaging. *Clinical Neurophysiology*, *115*(10), 2195–2222. https://doi.org/10.1016/j.clinph.2004.06.001

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*(1), 167–202. https://doi.org/10.1146/annurev.neuro.24.1.167

Mirz, F., Ovesen, T., Ishizu, K., Johannsen, P., Madsen, S., Gjedde, A., & Pederson, C. B. (1999). Stimulus-dependent central processing of auditory stimuli: a PET study. *Scandinavian Audiology*, *28*(3), 161–169. https://doi.org/10.1080/010503999424734

Näätänen, R. (1982). Processing negativity: An evoked-potential reflection of selective attention. *Psychological Bulletin*, *92*(3), 605–640. https://doi.org/10.1037/0033-2909.92.3.605

Näätänen, R. (1988). Implications of ERP data for psychological theories of attention. *Biological Psychology*, 26(1–3), 117–163. https://doi.org/10.1016/0301-0511(88)90017-8

Näätänen, R., Gaillard, A. W. K., & Varey, C. A. (1981). Early attention effect on evoked potential as a function of inter-stimulus interval. *Biological Psychology*, *13*, 173–187. https://doi.org/10.1016/0301-0511(81)90034-X

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology*, *24*(4), 375–425. https://doi.org/10.1111/j.1469-8986.1987.tb00311.x

Nielsen-Bohlman, L., Knight, R. T., Woods, D. L., & Woodward, K. (1991). Differential auditory processing continues during sleep. *Electroencephalography and Clinical Neurophysiology*, *79*(4), 281–290.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*(1), 97–113.

Pantev, C., Bertrand, O., Eulitz, C., Verkindt, C., Hampson, S., Schuierer, G., & Elbert, T. (1995). Specific tonotopic organizations of different areas of the human auditory cortex revealed by simultaneous magnetic and electric recordings. *Electroencephalography*

and Clinical Neurophysiology, 94(1), 26–40. https://doi.org/10.1016/0013-4694(94)00209-4

Pascual-Marqui, R. D. (2007). Discrete, 3D distributed, linear imaging methods of electric neuronal activity. Part 1: Exact, zero error localization. *arXiv*. https://arxiv.org/abs/0710.3341

Pascual-Marqui, R. D. (2009). Theory of the EEG inverse problem. In S. Tong & N. V. Thakor (Eds.), *Quantitative EEG Analysis: Methods and Clinical Applications* (pp. 121–140). Artech House.

Picton, T. W., Alain, C., Woods, D. L., John, M. S., Scherg, M., Valdes-Sosa, P., Bosch-Bayard, J., & Trujillo, N. J. (1999). Intracerebral sources of human auditory-evoked potentials. *Audiology and Neurotology, 4*(2), 64–79. https://doi.org/10.1159/000013823

Ramnani, N., & Owen, A. M. (2004). Anterior prefrontal cortex: Insights into function from anatomy and neuroimaging. *Nature Reviews Neuroscience, 5*(3), 184–194. https://doi.org/10.1038/nrn1343

Ranganath, C., Johnson, M. K., & D'Esposito, M. (2003). Prefrontal activity associated with working memory and episodic long-term memory. *Neuropsychologia, 41*(3), 378–389. https://doi.org/10.1016/s0028-3932(02)00169-0

Rif, J., Hari, R., Hämäläinen, M. S., & Sams, M. (1991). Auditory attention affects two different areas in the human supratemporal cortex. *Electroencephalography and Clinical Neurophysiology*, *79*(6), 464–472. https://doi.org/10.1016/0013-4694(91)90166-2

Ross, B., & Tremblay, K. (2009). Stimulus experience modifies auditory neuromagnetic responses in young and older listeners. *Hearing Research, 248*(1–2), 48–59. https://doi.org/10.1016/j.heares.2008.11.012

Sarazin, M., Pillon, B., Giannakopoulos, P., Rancurel, G., Samson, Y., & Dubois, B. (1998). Clinicometabolic dissociation of cognitive functions and social behaviour in frontal lobe lesions. *Neurology, 51*(1), 142–148. https://doi.org/10.1212/wnl.51.1.142

Schröger, E., Marzecová, A., & SanMiguel, I. (2015). Attention and prediction in human audition: a lesson from cognitive psychophysiology. *European Journal of Neuroscience, 41*(5), 641–664. https://doi.org/doi:10.1111/ejn.12816

Steiner, G. Z., Barry, R. J., & Gonsalvez, C. J. (2016). Sequential processing and the matching-stimulus interval effect in ERP components: An exploration of the mechanism using multiple regression. *Frontiers in Human Neuroscience, 10,* 1–14. https://doi.org/10.3389/fnhum.2016.00339

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology*, *38*(4), 387–401. https://doi.org/10.1016/0013-4694(75)90263-1

Timm, J., SanMiguel, I., Saupe, K., & Schröger, E. (2013). The N1-suppression effect for self-initiated sounds is independent of attention. *BMC Neuroscience*, *14*(2), 1–11 (2013). https://doi.org/10.1186/1471-2202-14-2

Tucker, L. R. (1951). A method for synthesis of factor analysis studies (Personnel Research Section Report No. 984). Washington, DC: Department of the Army.

van der Kallen, B. F., Rijpkema, G., van Erning, L. J., Merx, J. L., Horstink, M. W., & Thijssen, H. O. (1996). Functional MRI: imaging of motor cortex function. *Nederlands Tijdschrift voor Geneeskunde*, *140*(5), 248–254.

Vaughan, H. G., Jr., & Ritter, W. (1970). The sources of auditory evoked responses recorded from the human scalp. *Electroencephalography and Clinical Neurophysiology*, *28*(4), 360–367. https://doi.org/10.1016/0013-4694(70)90228-2

Wagner, M., Roychoudhury, A., Campanelli, L., Shafer, V. L., Martin, B., & Steinschneider, M. (2016). Representation of spectro-temporal features of spoken words within the P1-N1-P2 and T-complex of the auditory evoked potentials (AEP). *Neuroscience Letters, 614*, 119–126. https://doi.org/10.1016/j.neulet.2015.12.020

Wessel, J. R. (2018). Prepotent motor activity and inhibitory control demands in different variants of the go/no-go paradigm. *Psychophysiology*, *55*(3), Article e12871. https://doi.org/10.1111/psyp.12871

Wolpaw, J. R., & Penry, J. K. (1975). A temporal component of the auditory evoked response. *Electroencephalography and Clinical Neuropsychology*, *39*(6), 609–620. https://doi.org/10.1016/0013-4694(75)90073-5

Woods, D. L. (1995). The component structure of the N1 wave of the human auditory evoked potential. *Electroencephalography and Clinical Neuropsychology*, *44*, 102–109.

Woods, D. L., Alho, K., & Algazi, A. (1993). Intermodal selective attention: Evidence for processing in tonotopic auditory fields. *Psychophysiology*, *30*(3), 341–355. https://doi.org/10.1111/j.1469-8986.1993.tb03355.x

Woods, D. L., Knight, R. T., & Scabini, D. (1993). Anatomical substrates of auditory selective attention: Behavioural and electrophysiological effects of temporal and parietal lesions. *Cognitive Brain Research*, *1*(4), 227–240. https://doi.org/10.1016/0926-6410(93)90007-r

Chapter 3 Supplementary Material

S1.1. Overview

In this study, Go/NoGo ERP difference waveforms were calculated to identify the negative difference (Nd) traditionally used to quantify Processing Negativity (PN; Alho et al., 1990; Näätänen, 1982). Particular interest was also given to the early PN (Nd), as it was considered to reflect a matching process, indicating that participants were proactively maintaining an attentional trace (or representation) of sensory information to facilitate target processing (Hillyard & Kutas, 1983; Näätänen, 1982; Schröger et, 2015).

Two auditory Go/NoGo tasks were used in this study, which required participants to respond to Go (target) tones, and ignore NoGo (nontarget) tones; these tasks were similar to those used to study PN in the past. Early PN (Nd) is a frontal negativity that occurs between 50–250 ms poststimulus; although, its latency can vary for several reasons (see Näätänen's, 1982 review). Accordingly, we examined the entire stimulus-locked epoch (-100 to +750 ms) for signs of Nd. Due to the task-relevance of the Go tone, PN (Nd) was expected to be identified in relation to Go stimuli; hence, difference waveforms were calculated for each subject by subtracting their mean NoGo ERP waveforms from their averaged Go ERP data. Further confirmation of PN (Nd) was expected to be shown using a stimulus probability effect, replicating the positive relationship between Nd amplitude and target stimulus probability, found by Alho et al. (1990).

S1.2. ERP outcomes

The Grand Mean (GM) raw ERPs and difference waveforms computed for each condition and task are displayed in Figure S1, respectively. It is clear in the Go - NoGo difference waveforms that the 50–250 ms poststimulus period was positive across the scalp. Indeed, the GM raw frontal amplitude (averaged over F3, Fz, F4, and FCz) over that timeframe was .02 (*SD* = .54 μV) and .99 (*SD* = .69 μV) in the equiprobable and frequent-Go tasks, respectively. This finding demonstrated that there was no Nd evident in the expected time window in either task.

In Figure S1 a large negative difference wave is also evident at Fz and Cz between ~ 250-450 ms poststimulus. That negative difference was tentatively considered a late candidate for PN (Nd); however, after closer inspection it was instead decided to reflect a relative difference between the Go and NoGo P3, given its alignment with the frontocentral NoGo P3 in each task; this is discussed briefly in the main article. Overall, these findings indicate that no traditional PN (Nd) wave was evident to target stimuli in either task.

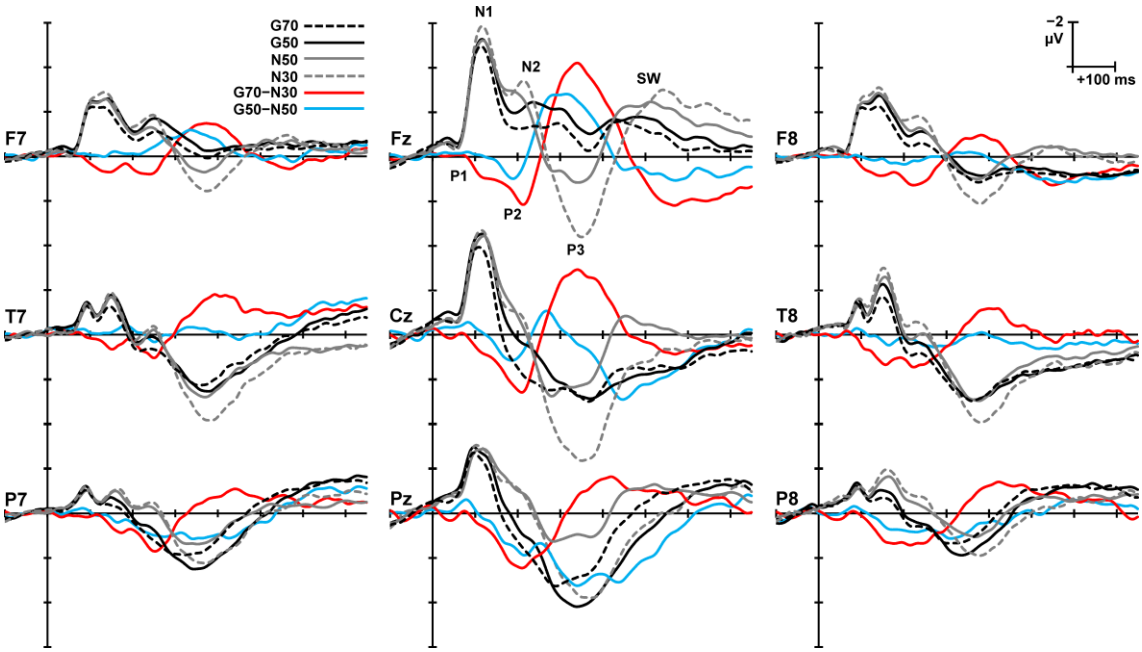


Figure S1. Grand Mean (GM) raw ERPs for each condition, and the difference waveforms calculated for the equiprobable (i.e., G50 − N50; Blue) and frequent-Go (i.e., G70 − N30; Red) variants of the auditory Go/NoGo task.

References

Alho, K., Lavikainen, J., Reinikainen, K., Sams, M., & Näätänen, R. (1990). Event-related brain potentials in selective listening to frequent and rare stimuli. *Psychophysiology, 27*(1), 73–86. https://doi.org/10.1111/j.1469-8986.1990.tb02183.x

Hillyard, S. A., & Kutas, M. (1983). Electrophysiology of cognitive processing. *Annual Reviews of Psychology, 34*, 33–61. https://doi.org/10.1146/annurev.ps.34.020183.000341

Näätänen, R. (1982). Processing negativity: An evoked-potential reflection of selective attention. *Psychological Bulletin, 92*(3), 605–640. https://doi.org/10.1037/0033-2909.92.3.605

Schröger, E., Marzecová, A., & SanMiguel, I. (2015). Attention and prediction in human audition: a lesson from cognitive psychophysiology. *European Journal of Neuroscience, 41*(5), 641–664. https://doi.org/doi:10.1111/ejn.12816

Chapter 4. Auditory Stimulus- and Response-Locked ERP Components and Behaviour

Foreword

This chapter features the second published journal article of this thesis, which investigated the functional significance of the ERP components associated with auditory Go processing in the equiprobable task, by analysing stimulus- and response-locked ERP averaging effects on PCA component amplitudes. The equiprobable Go ERP and behavioural data from Experiments 1 and 2 were combined to improve the statistical power and the ERP signal-to-noise ratio in this investigation. Since it was published in *Psychophysiology*, small adjustments have been made to the accepted article in this chapter to clarify the introduction and update the interpretation of the N1 components, so that the component labels are consistent with conceptual advances in Chapter 3. Minor changes were also made to the accepted paper by the journal editors prior to publication. A copy of the published manuscript is printed in Appendix C for reference.

Citation

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Author Contributions

JSF and RJB conceptualised this study. JSF performed the data collection, analyses, and interpretation of the outcomes under the supervision of RJB and GZS. The journal article was drafted and finalised by JSF following critical revisions provided by RJB and GZS. All authors approved the final article prior to submission.

Mr Jack S. Fogarty	Prof. Robert J. Barry	A/Prof. Genevieve Z. Steiner
PhD Candidate	Primary Supervisor & Co-author	Co-supervisor & Co-author
June 11, 2020	June 11, 2020	June 11, 2020

Abstract

To clarify the functional significance of Go event-related potential (ERP) components, this study aimed to explore stimulus- and response-locked ERP averaging effects on the series of ERP components elicited during an auditory Go/NoGo task. Go stimulus- and response-locked ERP data from 126 healthy young adults (M_{age} = 20.3, *SD* = 2.8 years, 83 female) were decomposed using temporal principal components analysis (PCA). The extracted components were then identified as stimulus-specific, response-specific, or common to both stimulus- and response-locked data. ANOVAs were then used to test for stimulus- versus response-locked averaging effects on common component amplitudes to determine their primary functional significance (i.e., stimulus- or response-related). Go stimulus- and response-related component amplitudes were then entered into stepwise linear regressions predicting the reaction time (RT), RT variability, and omission errors. Nine ERP components were extracted from the stimulus- and response-locked data, including N1b, N1c, P2, response-related N2 (RN2), motor potential (MP), P3b, P420, and two slow wave components; SW1 and SW2. N1b, N1c, and P2 were stimulus-specific, whereas, RN2, MP, and P420 were response-specific; P3b, SW1, and SW2 were common to both data sets. P3b, SW1, and SW2 were significantly larger in the response-locked data, indicating that they were primarily response-related. RT, RT variability, and omission errors were predicted by various stimulus- and response-related components, providing further insight into ERP markers of auditory information processing and cognitive control. Further, the results of this study indicate the utility of quantifying some common components (i.e., Go P3b, SW1, and SW2) using the response-locked ERP.

Keywords: ERPs, auditory processes, behaviour, cognitive control, information processing

1. Introduction

Averaging EEG data epochs time-locked (or synchronised) to the same repeated event increases the resolution of event-related potentials (ERPs). This *averaging effect* occurs as event-unrelated (unsynchronised) or latency-variable data in the individual epochs are attenuated, blurred, or filtered out of the averaged ERP data, like electrical artefact or noise (Poli et al., 2010). In previous research, ERP averaging (or blurring) effects have been studied to clarify the functional significance of ERP components, by comparing component amplitudes averaged to different events (e.g., stimulus vs. response onset). In this study, *Go* stimulus- and response-locked ERP data were compared to clarify ERP averaging effects and the functional significance of Go ERP components in an auditory equiprobable Go/NoGo task.

The Go/NoGo task is a two-choice reaction time (RT) task variant that requires a motor response to Go stimuli, but no response to NoGo stimuli. This paradigm is useful for studying basic information and control processing, as participants must detect and discriminate between stimuli, and selectively activate the appropriate behavioural response. In equiprobable variants of this task, Go and NoGo stimulus probabilities are balanced. This is the most efficient design for Go and NoGo data acquisition (Pfefferbaum et al., 1985), which may explain why equiprobable tasks are the most commonly used Go/NoGo variant (Wessel, 2018).

Auditory Go processing in the equiprobable task is associated with a series of stimulus-locked ERP components: P1, N1 (comprising several subcomponents: Näätänen & Picton, 1987), P2, N2c, P3b, and Slow Wave (SW). Those components are also overlapped by movement-related cortical potentials, involving response-locked components like the frontally negative Motor Potential (MP), the Correct Response Negativity (CRN), or the Reafferent Potential (Bötzel et al., 1997; Coles et al., 2001; Di Russo et al., 2017; Gerbrandt et al., 1973; Shibasaki & Hallett, 2006; Vaughan et al., 1968; Vidal et al., 2000). These stimulus- and response-locked components are considered to index brain functioning at distinct processing stages, providing researchers with discrete electrophysiological measures of the cognitive functioning related to information processing and motor control.

P1, N1 and P2 are generally associated with sensory and perceptual processes, including sensory gating, selective attention, and stimulus identification (Crowley & Colrain, 2004; Lijffijt et al., 2009; Näätänen & Picton, 1987). In contrast, N2c, P3b, and SW are often interpreted as reflecting either stimulus or response processes. For instance, N2c (or "the Go N2") is frequently linked to target classification, conflict monitoring, or response selection (Folstein & Van Petten, 2008; Larson et al., 2014; Nieuwenhuis et al., 2003; Yeung et al., 2004). P3b is also related to "context updating" (Donchin & Coles, 1988; Donchin et al., 1997), the reactivation of a stimulus-response pattern (Verleger et al., 2016), or response monitoring (Verleger et al., 2005). SW (including subcomponents, SW1 and SW2: Fogarty et al., 2019) is suggested to reflect information processing, response evaluation, or motor preparation for subsequent trials (Desmedt

& Debecker, 1979; Friedman, 1984; García-Larrea & Cézanne-Bert, 1998; Rohrbaugh et al., 1978).

Investigating the differences between stimulus- and response-locked ERP data can help to clarify functionally ambiguous ERP components like N2c, P3b, and SW. However, few studies have actually tested ERP averaging effects in the Go/NoGo task, and those have shown relatively inconsistent results.

In an auditory Go/NoGo task featuring rare targets (i.e., a classic oddball task), Goodin, Aminoff, and Mantle (1986) discovered that N2c was enhanced in stimulus-locked ERP data; whereas Go "P165" (perhaps equivalent to P2) and P3b amplitudes were larger when averaged in relation to the onset of motor responses. In contrast, Verleger et al. (2005) found no differences between the stimulus- and response-locked P3b in a two-choice task requiring left- or right-handed responses to alternate stimuli; this provided key evidence suggesting that P3b represents cognitive activity that is central to both stimulus and response processing. Saville et al. (2011) have since corroborated this finding at the single-trial level in a visual 1-back task, which also required participants to activate left- or right-handed responses.

More recently, Nguyen et al. (2016) compared a stimulus-locked NoGo N2 to response-locked error-related negativity (ERN) in a visual Go/NoGo paradigm, showing that increased N2 amplitudes following partial errors may be explained by greater error monitoring (an overlap of the ERN). Other studies have also explored stimulus- and response-locked ERPs to investigate error processing in choice-RT tasks, often in relation to correct ERPs (Falkenstein et al., 1991; Vidal et al., 2003). These ERP studies were designed to investigate the ERN; however, they also suggest that Go P3b and SW may be smaller in stimulus-locked averages due to overlapping ERN or CRN activity. Blind signal separation, such as Principal Components Analysis (PCA), could help separate these factors in stimulus- and response-locked data to determine whether P3 or SW averaging effects are distinct from those overlapping negativities. The wider error-related ERP literature is not considered further in this study as the focus is on correct Go processing; interested readers are directed to the reviews by Coles et al. (2001), Gehring et al. (2018), and Larson et al. (2014) for more on that topic.

Berchicci et al. (2016), in a large sample (n = 140), studied ERP averaging effects on a broad range of components using a visual equiprobable Go/NoGo task: P1 and N1 were larger in the stimulus-locked data, supporting their established relationship with stimulus processing (e.g., Liégeois-Chauvel et al., 1994; Lijffijt et al., 2009; Näätänen & Picton, 1987). P3b was larger in response-locked data, consistent with Goodin et al. (1986). However, surprisingly, Berchicci et al. (2016) did not identify the typical Go P2, nor any averaging effect on N2c (which was expected to be larger in response-locked data, consistent with conflict theory). Despite that, these results are considered to be more robust than earlier findings, which were derived using far smaller sample sizes ($n \leq 12$).

Due to the limited and inconsistent research into Go stimulus- and response-locked averaging effects, it was unclear which outcomes should be considered reliable, or whether any of the earlier findings would apply to ERP components in auditory equiprobable Go/NoGo tasks. The previous studies also used traditional ERP component amplitude measures (e.g., peak-to-peak or mean area), which are not ideal for isolating discrete ERP components, not to mention latent subcomponents (Donchin, 1966; Donchin & Heffley, 1978). Also, the similarity of matching stimulus- and response-locked components were not assessed prior to their comparison, which makes it difficult to ascertain the validity of each contrast.

The purpose of this research was to clarify the stimulus- and response-locked averaging effects on ERP components that are common to many two-choice tasks, and primarily, to elucidate the functional significance of the components associated with successful auditory Go processing. To accomplish that, this study aimed to compare the series of Go stimulus- and response-locked ERP components elicited in healthy young adults during the completion of an auditory equiprobable Go/NoGo task. The outcomes of this investigation were expected to provide valuable insight into the significance of several ERP components that are commonly used to measure cognitive functioning in a variety of two-choice paradigms; these findings may also have important implications regarding the quantification of those components.

To address the limitations of the previous Go/NoGo research, and extend on their findings, this study used temporal PCA to quantify and compare the Go stimulus- and response-locked components. Unlike the traditional ERP measures used in the past, temporal PCA with Varimax rotation extracts orthogonal latent components according to patterns of covariance in the ERP data, enabling the quantification and analysis of discrete ERP components (and subcomponents), while minimising misallocation of variance (Barry et al., 2016; Dien & Frishkoff, 2005; Donchin & Heffley, 1978; Kayser & Tenke, 2003). Nguyen et al. (2016) and Saville et al. (2011) also used PCA in their comparative stimulus and response-locked research, although the method was applied only to the stimulus-locked ERP data. To our knowledge, the present study reflects the first systematic comparison of the PCA factor series related to correct Go stimulus- and response-locked data in this task, providing novel insight into successful auditory Go processing, common ERP components, and ERP averaging effects in this popular Go/NoGo variant.

Following the general interpretation of averaging effects (Berchicci et al., 2016; Poli et al., 2010), ERP components here that were specific (unique) or larger to one event type were associated *primarily* with that type of processing. Moreover, because a purpose of this study was to clarify ERP component functionality, this categorisation scheme was then used to direct further analyses between Go component amplitudes and behaviour.

Following prior research, it was hypothesised that Go P1, N1, and P2 would primarily reflect stimulus-related processing (i.e., they would be unique or larger in stimulus-locked vs.

response-locked data), consistent with their connections to early sensory and perceptual processing in the broader ERP literature (Crowley & Colrain, 2004; Lijffijt et al., 2009; Näätänen & Picton, 1987). In contrast, the N2c, P3b, and SW components were predicted to be primarily response-related (i.e., larger in response-locked vs. stimulus-locked data), following a range of studies suggesting that those components index response processes (e.g., Falkenstein et al., 1994; Gratton et al., 2018; Nieuwenhuis et al., 2003; Rohrbaugh et al., 1978; Verleger et al., 2016). Response-locked components such as the MP, CRN, or RAP were also anticipated in this study, however, it was uncertain which of those components would be extracted, and how those components would relate to the stimulus-locked processing sequence in this paradigm. All subsequent behavioural analyses were exploratory.

2. Method

2.1. Sample demographics and eligibility criteria

One-hundred and twenty-six students (M_{age} = 20.3, *SD* = 2.8 years, 83 female) from the University of Wollongong volunteered through the School of Psychology Research Participation Scheme. Participants were healthy right-handed young adults (aged 18–35 years), with no self-reported ongoing mental or central neurological complaints, and no previous head injuries. Participants abstained from caffeine/tobacco (≥ 4 hours) and other psychoactive substances (≥ 12 hours) prior to their testing session. Each participant was screened against these criteria using a self-report questionnaire, and provided informed consent before testing. This procedure was approved by the University of Wollongong and Illawarra Shoalhaven Local Health District Human Research Ethics Committee (HE09/220). Stimulus-locked ERP data from ~50 % of this sample have been analysed previously in Fogarty, Barry, and Steiner (2019), and N was increased here to substantially enhance the robustness of this novel stimulus- and response-locked PCA investigation.

2.2. Physiological recording and setup

Continuous EEG data from DC to 30 Hz were recorded from 30 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2) and M2, grounded by an electrode at AFz and referenced to M1. Four electrodes were also placed above and below the left eye, and next to the outer canthi of each eye, to record continuous electrooculographic (EOG) data. The EEG and EOG data were all recorded at 1000 Hz using a Neuroscan SynAmps2 amplifier, and electrodes were all sintered Ag/AgCl with impedances below 5 kΩ.

2.3. Tasks and procedure

As reported in Fogarty et al. (2019), participants were seated in a dark sound-attenuated room to complete an EOG calibration task and an auditory equiprobable Go/NoGo task. The Go/NoGo task involved two blocks of 150 randomly shuffled tones (1000 and 1500 Hz),

presented at 60 dB SPL for 80 ms (including 15 ms rise/fall times) through circumaural headphones, using an SOA of 1250 ms. Global Go stimulus probability was 50 %, and Go and NoGo tone frequency was counterbalanced across blocks. Block order was also alternated across subjects.

Participants were instructed to respond to Go tones as quickly and as accurately as possible with a button-press from their right hand. A Go tone example, and a short ten trial practice (50 % Go) were provided before each block, which was repeated until the participant understood the task. A white fixation cross was also displayed in front of participants throughout the task to minimise eye/head movement.

2.4. Data quantification and measurement

2.4.1. Go behavioural performance

Go accuracy was represented by the rate of omission errors (i.e., misses), and reaction time (RT) was measured in ms. Extreme RTs (exceeding $M_{RT} \pm 2$ *SD*) within subjects were marked as RT errors. Trials containing any errors were removed so that only *successful* Go trials remained. Measures of mean Go RT and RT variability (RTV) (the intrasubject *SD* of RT) were then computed for analysis, using only the successful trials remaining after ERP artefact rejection.

2.4.2. ERPs and PCAs

EEG data were EOG corrected (Croft & Barry, 2000), re-referenced to digitally linked mastoids, low-pass filtered (FIR 25 Hz, 24 dB/Octave, zero-phase shift), and then epoched twice: relative to the successful Go stimuli (−100 to +750 ms) and individual RTs (−450 to +400 ms) in Neuroscan (Compumedics v. 4.5). The corresponding stimulus- and response-locked epochs were then paired and baselined to the average of the same prestimulus period in Matlab (The Mathworks, v. 8.0, R2012b). Trials including stimulus- or response-locked data exceeding ±100 μV were then rejected to remove artefactual data while maintaining consistent datasets associated with each event. The final accepted epochs were then averaged to generate mean stimulus- and response-locked ERPs for each participant.

The participants' averaged stimulus- and response-locked ERP data were submitted to separate temporal PCAs in Matlab (The Mathworks, v. 8.0, R2012b). Each PCA used the covariance matrix with Kaiser normalisation and unrestricted Varimax rotation. The Matlab functions used for this procedure were provided by Kayser and Tenke (2003) (http://bit.ly/2oX0etA), but slightly modified to avoid the removal of the grand mean ERP waveform from each case prior to computing the PCA component waveforms; this preserves the relationship between the input and output data, enabling the extracted PCA components to be considered directly in terms of their ERP amplitudes (see Barry et al., 2016; Dien, 2010). The case to component ratio in each PCA was 4.45 (3780 cases: 126 files × 30 sites; 850 components: timepoints/variables), which according to the prevailing rule of thumb, is approximately the ratio needed to achieve an acceptable level of stability in component patterns (Gorsuch, 1983).

The PCA method described above outputs factors in hierarchical order (of unique ERP variance), with their peak latency, and peak topography (i.e., the amplitude at each scalp derivation at the peak latency). Factors explaining ≥ 1 % of unique variance were retained for further analyses, and were identified as ERP components based on their temporal and topographic features, following previous ERP research.

To facilitate the comparability between the stimulus- and response-locked ERP outcomes, the grand mean RT was added to the latency of the response-locked ERP data so that they could be displayed relative to stimulus onset. ERP/PCA components that were unique to stimulus- or response-locked data were considered to be *stimulus-specific* or *response-specific*, respectively; whereas, those that were identified in both stimulus- and response-locked data were referred to as *common* ERP components.

2.5. Statistical analyses

2.5.1. Topographical analyses

The peak topographies of common components were compared between event types using Pearson's correlations conducted over all 30 scalp sites. The peak topography of each component was then defined statistically using 3 × 3 repeated measures ANOVAs with planned orthogonal contrasts of the peak amplitude data at nine core sites, representing the sagittal (Frontal [F3, Fz, F4], Central [C3, Cz, C4], and Parietal [P3, Pz, P4]) and coronal plane (Left [F3, C3, P3], Midline [Fz, Cz, Pz], Right [F4, C4, P4]). For the N1c component, data from F7/8, T7/8, and P7/8 replaced the Left and Right sites to account for its topographical focus at temporal sites (similar to Barry et al., 2016). If components were common, *event* was added as an additional two-level factor (i.e., stimulus vs. response) to evaluate averaging effects. Significant averaging effects revealed the optimal event synchronisation for common components, and the larger component in each pair was considered to be the 'optimal' variant. No adjustments to alpha were necessary, as the number of planned contrasts was lower than the degrees of freedom for effect (Tabachnik & Fidell, 2013). Greenhouse-Geisser corrections were also unnecessary as single degree-of-freedom contrasts are not influenced by violations of sphericity (O'Brien & Kaiser, 1985). Each F test had (1, 125) degrees of freedom, and significant ($p < .05$) and approaching-significant ($.05 \leq p \leq .10$) F tests are reported (the latter are not discussed).

2.5.2. Regression analyses of ERP components and behaviour

Linear multiple regressions were conducted in SPSS (V21) to link ERP component amplitudes with the behavioural outcomes. ERP component amplitudes were calculated within subjects, as the mean across the electrodes reflecting the component's largest amplitudes at the component's peak latency (electrode selection was guided by the component headmaps and the topographic analyses described in 2.5.1). ERP component amplitudes were submitted as the predictors of each behavioural variable (i.e., RT, RTV, and omission rate) using a stepwise method, with entry and removal criteria at $\alpha = .05$ and $\alpha = .10$, respectively. Only event-specific

and ‘optimal’ components were subject to these analyses, as they were considered to reflect the best measure of the components related to successful Go processing. This also circumvents any issues of multicollinearity that might arise if matching stimulus- and response-locked data were both included in the same regression.

3. Results

3.1. Go trial and performance outcomes

The average number of Go trials accepted across participants was 139.1 (*SD* = 7.1). Across participants, the grand mean RT was 369.7 ms (*SD* = 50.9) and the grand mean RTV was 76.7 ms (*SD* = 24.1). The grand mean Go omission error rate was 1.5 % (*SD* = 2.7).

3.2. Raw ERPs

The grand mean raw ERPs from three midline sites (Fz, Cz, and Pz) are presented in Figure 1. In the grand mean stimulus-locked ERP, P1 is identifiable as the minor positive-going peak at Fz, ~50 ms poststimulus. That is followed by a large N1 and a minor P2/N2 complex (notable at Fz), at ~100 and 200 ms poststimulus, respectively. After ~300 ms, a broad P3 and SW dominate the remaining ERP trace. In the grand mean response-locked ERP, a large frontal negativity peaks ~200 ms after stimulus onset, reflecting a response-related N2 (RN2). RN2 is followed by a parietal P3, and a frontal peak of the MP (Shibasaki & Hallett, 2006), which peak almost simultaneously with the grand mean RT. The MP is succeeded by a response-locked SW, featuring a central positivity at ~450 ms (SW1), and a frontoparietal negativity beginning ~550 ms poststimulus (SW2).

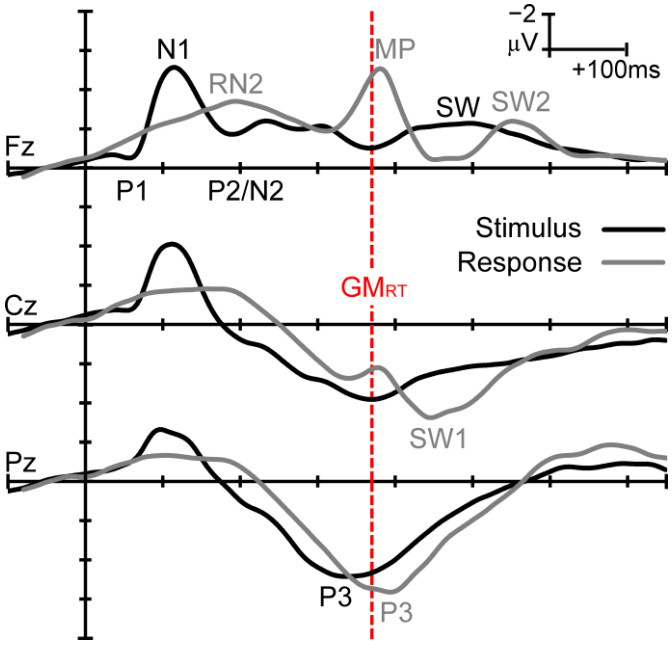

Figure 1. Grand mean raw stimulus- and response-locked ERPs at three midline electrode sites, with stimulus- and response-locked components labelled in black and grey, respectively. The grand mean RT (GM_{RT}) is marked by the dashed red line.

3.3. PCA outcomes

Figure 2 displays the separate factor loadings for the stimulus- and response-locked PCA components identified in this study. Six components were identified in relation to each event. This involved (in latency order) a stimulus-locked N1b and N1c (two subcomponents of the N1: Näätänen & Picton, 1987), P2, P3b, Go SW1, and SW2, explaining a total 92.5 % of the stimulus-locked ERP variance. From the response-locked ERP data, an RN2, P3b, MP, P420 (an unidentifiable parietal positivity), SW1 and SW2 were identified, accounting for 90.4 % of the total ERP variance related to the response.

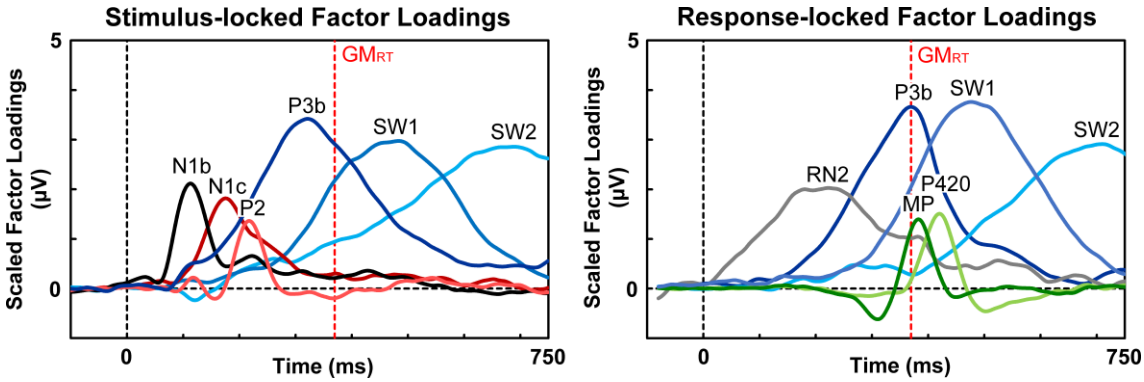

Figure 2. Stimulus- and response-locked scaled factor loadings for each component; grand mean RT (GM_{RT}) is marked by the dashed red line.

3.4. Topographical outcomes

Figure 3 depicts the peak topography and factor information for each of the 12 stimulus- and response-locked components extracted in this study. Nine distinct components were identified overall, including six unique event-specific components (i.e., stimulus-locked: N1b, N1c, P2; response-locked: RN2, MP, P420), and three common components that were identified in both stimulus- and response-locked data (i.e., P3b, SW1, and SW2). The peak topographies of the corresponding common components were strongly correlated ($r[28] \geq .94$, $p < .001$), showing that they were highly comparable. For brevity, only the averaging effects on common component topographies are reported here. The remaining statistical outcomes defining individual component topographies are summarised in Chapter 4 Supplementary Material (pp. 87–88).

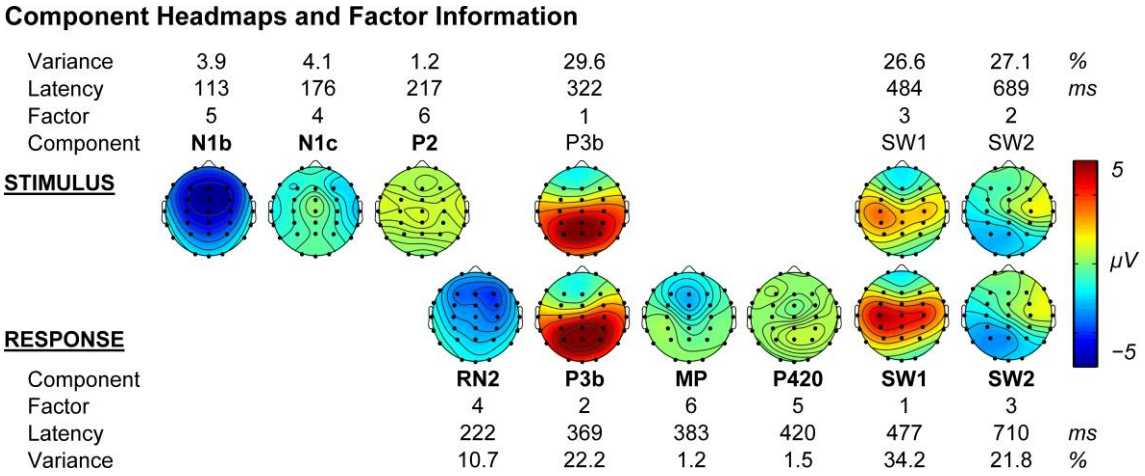

Figure 3. The stimulus- and response-locked ERP component headmaps, labels, and factor information; those with bolded labels were analysed in relation to behaviour.

3.5. ERP averaging effects

The averaging effects on P3b, SW1, and SW2 are presented in Table 1, and indicate that all three components were *primarily* response-related; this is also represented in Figure 3 and Figure 4, which illustrate the impact that stimulus- and response-locked averaging had on the common component headmaps and waveforms, respectively. The tabulated symbols outlining the topographical effects for P3b are also included in text to facilitate the interpretation of the statistical results; note that the reversals in Table 1 (as indicated by underlined effects) have also been applied here in text to improve readability.

Table 1

ERP Averaging Effects

	P3b			SW1			SW2		
Effect	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
RL > SL				57.19	< .001	.31	4.03	.047	.03
RL > SL × F > P	19.17	< .001	.13				25.20	< .001	.17
RL > SL × C > F/P	16.65	< .001	.12	174.82	< .001	.58	28.88	< .001	.19
RL > SL × L > R	37.40	< .001	.23				15.33	< .001	.11
RL > SL × M > L/R				26.88	< .001	.18			
RL > SL × F > P × L > R	7.20	.008	.05	3.73	.056	.03	6.95	.009	.05
RL > SL × F > P × M > L/R	34.18	< .001	.21				5.81	.017	.04
RL > SL × C > F/P × L > R	48.75	< .001	.28						
RL > SL × C > F/P × M > L/R	3.50	.064	.03	24.34	< .001	.16			

N.B. RL = response-locked; SL = stimulus-locked; F = frontal; C = central; P = parietal; F/P = frontoparietal mean; L = left hemisphere; M = midline; R = right hemisphere; L/R = hemispheric mean. Effects approaching significance are in grey text, and underlined effects are reversed for corresponding underlined results. Two relationship reversals within an effect represents a statistically-equivalent effect (e.g., C < F/P × M < L/R ≡ C > F/P × M > L/R).

When synchronised with the Go response, parietal P3b amplitudes were significantly enhanced (RL > SL × F < P and RL > SL × C < F/P), especially at the left (RL > SL × F < P × L > R) and midline sites (RL > SL × F < P × M > L/R); the right hemisphere was also increased (RL > SL × L < R), particularly at central sites (RL > SL × C > F/P × L < R). Significant main effects were found on SW1 and SW2, showing that their response-locked amplitudes were larger over the nine core scalp sites. Focal enhancements were also identified in relation to the response: SW1 positivity was further increased at the central sites and midline sites, and these effects interacted, illustrating a strong response-related enhancement at the vertex. SW2 negativity was strongly enhanced at parietal sites, and in the left hemisphere. The parietal enhancement was larger in both the midline and left hemisphere.

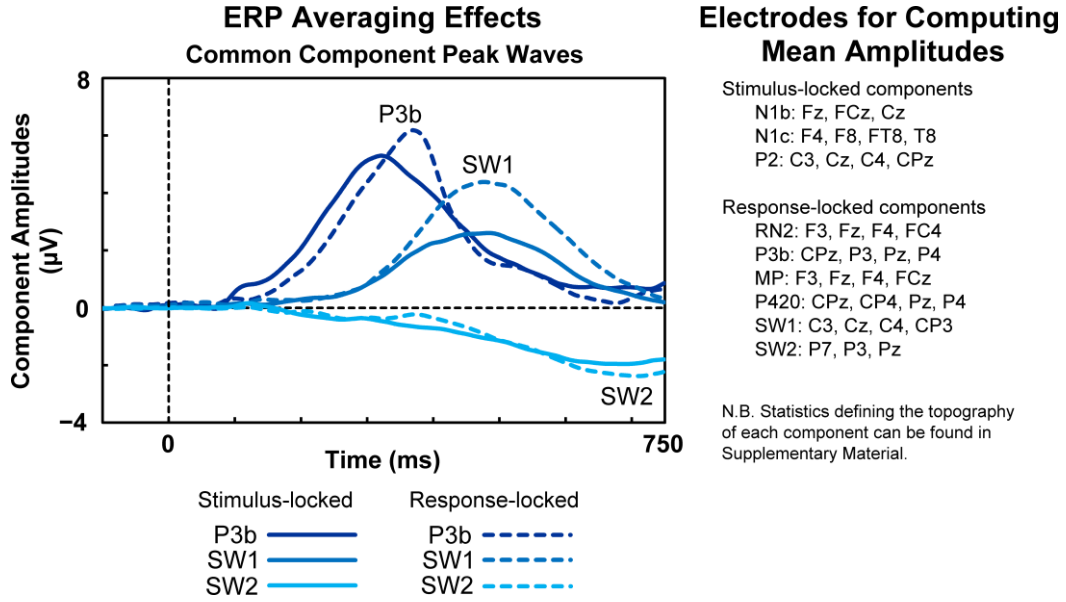

Figure 4. Left: A comparison of the common components (P3b, SW1, and SW2) at their peak electrode sites, illustrating the averaging effect between stimulus- and response-locked amplitudes. Right: The electrodes used to compute the mean peak amplitude of each component for behavioural analyses using multiple regression.

3.6. ERP components and behaviour

The ERP/PCA components that were subjected to behavioural analyses included the stimulus-specific N1b, N1c, and P2; the response-specific RN2, MP, and P420; and the optimal response-locked P3b, SW1, and SW2. The electrode sites used to calculate the mean peak amplitudes for each of these components are outlined in Figure 4, on the right.

The stepwise linear regressions showed that Go RTs were predicted by N1c, RN2, P420, and SW1 amplitudes: adjusted R^2 = .156, $F(4, 121) = 6.771$, $p < .001$. Specifically, faster RTs were related to smaller N1c (β = −.243, $t = -2.614$, $p = .010$), larger RN2 (β = .311, $t = 3.359$, $p = .001$), larger P420 (β = −.204, $t = -2.462$, $p = .015$), and larger SW1 amplitudes (β = −.236, $t = -2.850$, $p = .005$). Go RTV was predicted by P3b and P420: adjusted R^2 = .110, $F(2, 123) = 8.723$,

$p < .001$. Lower RTV was associated with larger P3b ($\beta = -.265$, $t = -3.130$, $p = .002$) and larger P420 amplitudes ($\beta = -.213$, $t = -2.519$, $p = .013$). Omission error rates were also predicted by P420: adjusted $R^2 = .040$, $F(1, 124) = 6.266$, $p = .014$. Fewer omission errors linked to larger P420 amplitudes ($\beta = -.219$, $t = -2.503$, $p = .014$, $R^2 = .048$).

4. Discussion

This study used a factor analytic approach to investigate and compare the series of stimulus- and response-locked ERP components in an auditory equiprobable Go/NoGo task, in order to clarify ERP averaging effects, and the functional significance of the ERP components associated with auditory *Go* (target) processing in healthy young adults. Nine components were extracted from the Go stimulus- and response-locked ERP data, including (in latency order) N1b and N1c (two N1 subcomponents: Näätänen & Picton, 1987), P2, RN2, P3b, MP, P420, and SW1 and SW2 (two SW subcomponents: Fogarty et al., 2019). These discrete components were specific (or unique) to either stimulus- or response-locked data, or common to both. The functionality of each common component was demonstrated by significant averaging effects, and this classification was then used to direct further analyses between the Go ERP (PCA) component series and behaviour.

Go P3b, SW1, and SW2 were common to both stimulus- and response-locked ERP datasets, although all three were significantly larger in the averaged response-locked data, demonstrating that these components represent neuronal activity that is primarily response-related. The P3b outcome here is consistent with findings in other Go/NoGo task variants (Berchicci et al., 2016; Goodin et al., 1986; *cf.* Verleger et al., 2005), whereas the significant averaging effects on SW1 and SW2 amplitudes reflect novel findings in this paradigm; perhaps comparable to SW observations in error trials (Falkenstein et al., 1991). These effects suggest that Go P3b, SW1 and SW2 (which are typically measured from stimulus-locked data) should be quantified and analysed as response-locked components. PCA is also considered to isolate these components from other potentials suggesting that these averaging effects are distinct from overlapping motor activity (*cf.* Falkenstein et al., 1991; Vidal et al., 2003). Further implications for each component are discussed alongside the behavioural findings below.

As expected, the N1 components (i.e., N1b and N1c) and P2 were primarily stimulus-related, supporting prior research linking those components to sensory and perceptual processing (e.g., Crowley & Colrain, 2004; Liégeois-Chauvel et al., 1994; Lijffijt et al., 2009; Näätänen & Picton, 1987). Additionally, further analyses showed that smaller N1c amplitudes (i.e., lower magnitude) predicted shorter RTs. This outcome could support links between N1 and the activation of stimulus-response processing (Bender et al., 2006), and that more efficient stimulus processing can lead to earlier responses, suggesting that the N1c component could be associated with stimulus categorisation.

RN2 amplitudes were negatively associated with RT, providing novel evidence for a control-related response-locked N2 component preceding the response (Folstein & Van Petten, 2008). This component has been considered to index response conflict (like N2c), although that is only possible if larger pre-response conflict signals can facilitate response selection or activation (Nieuwenhuis et al., 2003; *cf*. Larson et al., 2014; Yeung et al., 2004).

The response-locked P3b peaked in line with the grand mean RT ~370 ms poststimulus. P3b was larger when RTV was smaller, possibly reflecting a greater coupling between stimulus- and response-related activity (Saville et al., 2011). Together, in conjunction with the averaging effects identified in this study, these outcomes support hypotheses linking P3b to stimulus-response processing, although it is primarily response-related. This supports the notion that P3b context updating can involve response-related information to facilitate strategic task processing (*cf*. Donchin & Coles, 1988). Specifically, P3b could represent the updating of sensory, and in particular, motor or response-related representations in working memory (Brydges & Barceló, 2018). Alternatively, this finding could support the link between P3b and a 'tactical' reactivation of a stimulus-response pattern (Verleger et al., 2015, 2016). In successful Go trials, that would result in motor activation and movement-related sensory feedback, which could be marked by the frontal MP identified ~15 ms after the grand mean RT (Gerbrandt et al., 1973; Tarkka & Hallett, 1991). MP was not related to any behavioural outcomes in this study, which supports its conceptualisation as a simple motor (or reafferent) potential, as opposed to an endogenous component related to active cognitive control or behavioural regulation.

P420 was a novel response-specific positivity that was negatively associated with RT, RTV, and omission error rates. The identity of P420 is unclear; however, its morphology resembles that of the parietal error positivity (Pe: Falkenstein et al., 2000) and the small response-related portion of the P3 (R-P3) identified using RIDE, an iterative decomposition method used to separate stimulus- and response-locked (and intermediate) ERP waveforms from single trial EEG data (see Ouyang et al., 2011, 2015; Verleger et al., 2014, 2016). The latter (R-P3) is perhaps a more likely match for P420 considering that Pe should only be evident following response errors (Vidal et al., 2000). In that case, P420 could also be viewed in terms of tactical response processing or evaluation (Verleger et al., 2016). Linking P420 to response evaluation could accommodate its broad relationship with behavioural performance in this study.

The response-locked SW1 positivity increased with shorter RTs, which could be consistent with hypotheses linking SW1 and SW2 in the auditory Go/NoGo task to post-response evaluation and further planning or preparation for subsequent trials (Fogarty et al., 2019). This perspective builds on earlier research, which posits that late SW components reflect evaluation or memory-related processes (e.g., Friedman, 1984; García-Larrea & Cézanne-Bert, 1998), or preparatory processing in choice-response tasks (see, Desmedt & Debecker, 1979; Rohrbaugh et al., 1978).

Further considerations regarding this investigation refer to components that were not identified. Hypothetically, the absence of a stimulus-locked N2c in this study could suggest that the typical Go N2c is a response-related component, as anticipated. The small diffuse topography of the auditory N2c and its usual latency ~250 ms poststimulus (e.g., Melynyte et al., 2017; Fogarty et al., 2019) could suggest that it reflects a smearing of RN2 in stimulus-locked data, which would explain why larger RTV has been linked to smaller stimulus-locked N2c amplitudes (Fogarty et al., 2018). If this is the case, N2c's role in target stimulus processing would be questionable (*cf*. Goodin et al., 1986; Pritchard et al., 1991).

CRN and RAP also were not identified in this study. It is unclear why CRN was not extracted; however, it is possible that RAP might correspond with SW1, considering that the morphological features of the two components are almost identical (Bötzel et al., 1997; Di Russo et al., 2017; Kornhuber & Deecke, 2016; Shibasaki et al., 1980; Vaughan et al., 1968). This would imply that SW1 could reflect the processing of reafferent input, although further research is needed to explore this, perhaps by examining the links between SW1 and kinematic variables. Averaging data over RT bins (Friedman, 1984; Poli et al., 2010; Verleger et al., 2005), or perhaps using other ERP decomposition techniques (e.g., RIDE) in conjunction with PCA, could also help to elucidate additional components in this paradigm.

Alternatively, the current PCA approach may not have extracted a distinct N2c, CRN, or RAP if the time course of those components overlapped similar factors. The Varimax rotation in this study could have combined morphologically similar components into fewer factors to achieve a simpler orthogonal factor solution. This is expected to be less likely for N2c given that it is frequently separated using Varimax PCA in this task (e.g., Barry & De Blasio, 2013; Fogarty et al., 2018, 2019; Karamacoska, Barry, & Steiner, 2017, 2018; Karamacoska, Barry, Steiner, Coleman, & Wilson, 2018); although, it is possible that CRN or RAP were extracted with MP, P420, or SW1. Further research is needed to help distinguish these components; however, this study could suggest that those components may be described by fewer factors in this task, questioning their distinction in this paradigm and perhaps the broader ERP literature.

Unlike previous research examining the ERP components associated with simple equiprobable Go/NoGo task processing, this study used temporal PCA to extract and compare orthogonal stimulus- and response-locked ERP components and subcomponents for analysis. The outcomes clarified ERP averaging effects on a range of components, and in conjunction with behaviour, these findings provided novel insight into the Go processing series in the auditory equiprobable Go/NoGo task. Notably, Go P3b, SW1, and SW2 were primarily response-related, supporting theories linking those components to motor or response processing. This also suggests that P3b, SW1, and SW2 should be quantified as response-locked components to improve their analytical validity in future Go/NoGo research.

References

Barry, R. J., & De Blasio, F. M. (2013). Sequential processing in the equiprobable auditory Go/NoGo task: A temporal PCA study. *International Journal of Psychophysiology, 89*(1), 123–127. https://doi.org/10.1016/j.ijpsycho.2013.06.012

Barry, R. J., De Blasio, F. M., Fogarty, J. S., & Karamacoska, D. (2016). ERP Go/NoGo condition effects are better detected with separate PCAs. *International Journal of Psychophysiology, 106*, 50–64. https://doi.org/10.1016/j.ijpsycho.2016.06.003

Bender, S., Oelkers-Ax, R., Resch, F., & Weisbrod, M. (2006). Frontal lobe involvement in the processing of meaningful auditory stimuli develops during childhood and adolescence. *NeuroImage, 33*(2), 759–773. https://doi.org/10.1016/j.neuroimage.2006.07.003

Berchicci, M., Spinelli, D., & Di Russo, F. (2016). New insights into old waves. Matching stimulus- and response-locked ERPs on the same time-window. *Biological Psychology, 117*, 202–215. https://doi.org/10.1016/j.biopsycho.2016.04.007

Bötzel, K., Ecker, C., & Schulze, S. (1997). Topography and dipole analysis of reafferent electrical brain activity following the Bereitschaftspotential. *Experimental Brain Research, 114*, 352–361. https://doi.org/10.1007/PL00005643

Brydges, C. R., & Barceló, F. (2018). Functional dissociation of latency-variable, stimulus- and response-locked target P3 sub-components in task-switching. *Frontiers in Human Neuroscience, 12*, 1–14. https://doi.org/10.3389/fnhum.2018.00060

Coles, M. G., Scheffers, M. K., & Holroyd, C. B. (2001). Why is there an ERN/Ne on correct trials? Response representations, stimulus-related components, and the theory of error-processing. *Biological Psychology, 56*, 173–189. https://doi.org/10.1016/S0301-0511(01)00076-X

Croft, R. J., & Barry, R. J. (2000). EOG correction of blinks with saccade coefficients: A test and revision of the aligned-artefact average solution. *Clinical Neurophysiology, 111*(3), 444–451. https://doi.org/10.1016/S1388-2457(99)00296-5

Crowley, K. E., & Colrain, I. M. (2004). A review of the evidence for P2 being an independent component process: Age, sleep and modality. *Clinical Neurophysiology, 115*(4), 732–744. https://doi.org/10.1016/j.clinph.2003.11.021

Desmedt, J. E., & Debecker, J. (1979). Slow potential shifts and decision P350 interactions in tasks with random sequences of near-threshold clicks and finger stimuli delivered at regular intervals. *Electroencephalography and Clinical Neurophysiology, 47*, 671–679. https://doi.org/10.1016/0013-4694(79)90294-3

Dien, J. (2010). The ERP PCA Toolkit: An open source program for advanced statistical analysis of event-related potential data. *Journal of Neuroscience Methods, 187*(1), 138–145. https://doi.org/10.1016/j.jneumeth.2009.12.009

Dien, J., Frishkoff, G. A. (2005). Principal components analysis of event-related potential

datasets. In T. Handy (Ed.), *Event-related potentials: A methods handbook* (pp. 189–208). Cambridge, MA: MIT Press

Di Russo, F., Berchicci, M., Bozzacchi, C., Perri, R. L., Pitzalis, S., & Spinelli, D. (2017). Beyond the "Bereitschaftspotential": Action preparation behind cognitive functions. *Neuroscience and Biobehavioral Reviews, 78,* 57–81. https://doi.org/10.1016/j.neubiorev.2017.04.019

Donchin, E. (1966). A multivariate approach to the analysis of average evoked potentials. *IEEE Transactions of Biomedical Engineering, 13,* 131–139.

Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioural and Brain Sciences. 11*(3), 357–374. https://doi.org/10.1017/S0140525X00058027

Donchin, E., & Heffley, E. F. (1978). Multivariate analysis of event-related potential data: A tutorial review. In D. A. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (pp. 555–572). Washington, DC: U.S. Government Printing Office.

Donchin, E., Spencer, K. M., & Dien, J. (1997). The varieties of deviant experience: ERP manifestations of deviance processors. In G. J. M. Van Boxtel & K. B. E. Bocker (Eds.), *Brain and Behavior: Past, Present, and Future* (pp. 67–91). Tilburg University Press.

Falkenstein, M., Hohnsbein, J., & Hoormann, J. (1994). Effects of choice complexity on different subcomponents of the late positive complex of the event-related potential. *Electroencephalography and Clinical Neurophysiology, 92,* 148–160. https://doi.org/10.1016/0168-5597(94)90055-8

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroencephalography and Clinical Neurophysiology, 78*(6), 447–455. https://doi.org/10.1016/0013-4694(91)90062-9

Falkenstein, M., Hoormann, J., Christ, S., & Hohnsbein, J. (2000). ERP components on reaction errors and their functional significance: A tutorial. *Biological Psychology, 51,* 87–107. https://doi.org/10.1016/S0301-0511(99)00031-9

Fogarty, J. S., Barry, R. J., De Blasio, F. M., & Steiner, G. Z. (2018). ERP components and behavior in the auditory equiprobable go/no-go task: Inhibition in young adults. *Psychophysiology, 55*(7), Article e13065. https://doi.org/10.1111/psyp.13065

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2019). Sequential processing in the classic oddball task: ERP components, probability, and behavior. *Psychophysiology, 56*(3), Article e13300. https://doi.org/10.1111/psyp.13300

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2

component of the ERP: A review. *Psychophysiology, 45*(1), 152–170. https://doi.org/10.1111/j.1469-8986.2007.00602.x

Friedman, D. (1984). P300 and slow wave: the effects of reaction time quartile. *Biological Psychology, 18,* 49–71. https://doi.org/10.1016/0301-0511(84)90028-0

García-Larrea, L., & Cézanne-Bert, G. (1998). P3, positive slow wave and working memory load: a study on the functional correlates of slow wave activity. *Electroencephalography and Clinical Neurophysiology, 108,* 260–273. https://doi.org/10.1016/s0168-5597(97)00085-3

Gehring, W. J., Goss, B., Coles, M. G., Meyer, D. E., & Donchin, E. (2018). The error-related negativity. *Perspectives on Psychological Science*, *13*(2), 200-204. https://doi.org/10.1177/1745691617715310

Gerbrandt, L. K., Goff, W. R., & Smith, D. B. (1973). Distribution of the Human Average Movement Potential. *Electroencephalography and Clinical Neurophysiology*, *34*, 461–474. https://doi.org/10.1016/0013-4694(73)90064-3

Goodin, D. S., Aminoff, M. J., & Mantle, M. M. (1986). Subclasses of event-related potentials: response-locked and stimulus-locked components. *Annals of Neurology, 20,* 603–609. https://doi.org/10.1002/ana.410200508

Gorsuch, R. L. (1983). *Factor analysis* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Gratton, G., Cooper, P., Fabiani, M., Carter, C. S., & Karayanidis, F. (2018). Dynamics of cognitive control: Theoretical bases, paradigms, and a view for the future. *Psychophysiology, 55*(3), 1–29. https://doi.org/10.1111/psyp.13016

Karamacoska, D., Barry, R. J., & Steiner, G. Z. (2017). Resting state intrinsic EEG impacts on go stimulus-response processes. *Psychophysiology*, *54*(6), 894–903. https://doi.org/10.1111/psyp.12851

Karamacoska, D., Barry, R. J., Steiner, G. Z. (2018). Electrophysiological underpinnings of response variability in the Go/NoGo task. *International Journal of Psychophysiology, 134,* 159–167. https://doi.org/10.1016/j.ijpsycho.2018.09.008

Karamacoska, D., Barry, R. J., Steiner, G. Z., Coleman, E. P., & Wilson, E. J. (2018). Intrinsic EEG and task-related changes in EEG affect Go/NoGo task performance. *International Journal of Psychophysiology, 125,* 17–28. https://doi.org/10.1016/j.ijpsycho.2018.01.015

Kayser, J., & Tenke, C. E. (2003). Optimizing PCA methodology for ERP component identification and measurement: Theoretical rationale and empirical evaluation. *Clinical Neurophysiology, 114*(12), 2307–2325. https://doi.org/10.1016/S1388-2457(03)00241-4

Kornhuber, H. H., & Deecke, L. (2016). Brain potential changes in voluntary and passive movements in humans: Readiness potential and reafferent potentials. *Pflugers Archiv*

European Journal of Physiology, 468, 1115–1124. https://doi.org/10.1007/s00424-016-1852-3

Larson, M. J., Clayson, P. E., & Clawson, A. (2014). Making sense of all the conflict: A theoretical review and critique of conflict-related ERPs. *International Journal of Psychophysiology, 93*, 283–297. https://doi.org/10.1016/j.ijpsycho.2014.06.007

Liégeois-Chauvel, C., Musolin, A., Badier, J. M., Marquis, P., & Chauvel, P. (1994). Evoked potentials recorded from the auditory cortex in man: Evaluation and topography of the middle latency components. *Electroencephalography and Clinical Neurophysiology, 92*, 204–214. https://doi.org/10.1016/0168-5597(94)90064-7

Lijffijt, M., Lane, S. D., Meier, S. L., Boutros, N. N., Burroughs, S., Steinberg, J. L., Moeller, F. G., & Swann, A. C. (2009). P50, N100, and P200 sensory gating: Relationships with behavioral inhibition, attention, and working memory. *Psychophysiology, 46*(5), 1059–1068. https://doi.org/10.1111/j.1469-8986.2009.00845.x

Melynyte, S., Ruksenas, O., & Griskova-Bulanova, I. (2017). Sex differences in equiprobable auditory Go/NoGo task: Effects on N2 and P3. *Experimental Brain Research, 235*, 1565–1574. http://doi. org/10.1007/s00221-017-4911-x

Näätänen, R. (1982). Processing Negativity: An evoked-potential reflection of selective attention. *Psychological Bulletin, 92*(3), 605–640. http://dx.doi.org/10.1037/0033-2909.92.3.605

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24*(4), 375–425. https://doi.org/10.1111/j.1469-8986.1987.tb00311.x

Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective & Behavioral Neuroscience, 3*, 17–26. https://doi.org/10.3758/CABN.3.1.17

Nguyen, A. T., Moyle, J. J., & Fox, A. M. (2016). N2 and P3 modulation during partial inhibition in a modified go/nogo task. *International Journal of Psychophysiology, 107*, 63–71. https://doi.org/10.1016/j.ijpsycho.2016.07.002

O'Brien, R. G., & Kaiser, M. K. (1985). MANOVA method for analyzing repeated measures designs: An extensive primer. *Psychological Bulletin, 97*(2), 316–333. http://doi.org/10.1037/0033-2909.97.2.316

Ouyang, G., Herzmann, G., Zhou, C., & Sommer, W. (2011). Residue Iteration Decomposition (RIDE): A new method to separate ERP components on the basis of latency variability in single trials. *Psychophysiology, 48*(12), 1631–1647. https://doi.org/10.1111/j.1469-8986.2011.01269.x

Ouyang, G., Sommer, W., & Zhou, C. (2015). Updating and validating a new framework for

restoring and analyzing latency-variable ERP components from single trials with Residue Iteration Decomposition (RIDE). *Psychophysiology, 52,* 839–856. https://doi.org/10.1111/psyp.12411

Pfefferbaum, A., Ford, J. M., Weller, B. J., & Kopell, B. S. (1985). ERPs to response production and inhibition. *Electroencephalography and Clinical Neurophysiology, 60*(5), 423–434. http://doi.org/10. 1016/0013-4694(85)91017-X

Pires, L., Leitão, J., Guerrini, C., & Simões, M. R. (2014). Event-related brain potentials in the study of inhibition: Cognitive control, source localisation and age-related modulations. *Neuropsychology Review, 24*(4), 461–490. http://doi.org/10.1007/s11065-014-9275-4

Pritchard, W. S., Shappell, S. A., & Brandt, M. E. (1991). Psychophysiology of N200/N400: A review and classification scheme. In J. R. Jennings & P. K. Ackles (Eds.), *Advances in psychophysiology: A research annual* (Vol. 4, pp. 43–106). London: Jessica Kingsley.

Poli, R., Cinel, C., Citi, L., & Sepulveda, F. (2010). Reaction-time binning: A simple method for increasing the resolving power of ERP averages. *Psychophysiology*, *47*(3), 467–485. https://doi.org/10.1111/j.1469-8986.2009.00959.x

Rohrbaugh, J. W., Syndulko, K., & Lindsley, D. B. (1978). Cortical slow negative waves following non-paired stimuli: Effects of Task Factors. *Electroencephalography and Clinical Neurophysiology*, *45*, 551–567. https://doi.org/10.1016/0013-4694(78)90156-6

Saville, C. W. N., Dean, R. O., Daley, D., Intriligator, J., Boehm, S., Feige, B., & Klein, C. (2011). Electrocortical correlates of intra-subject variability in reaction times: Average and single-trial analyses. *Biological Psychology, 87*(1), 74–83. https://doi.org/10.1016/j.biopsycho.2011.02.005

Shibasaki, H., & Hallett, M. (2006). What is the Bereitschaftspotential? *Clinical Neurophysiology, 117*, 2341–2356. https://doi.org/10.1016/j.clinph.2006.04.025

Shibasaki, H., Barrett, G., Halliday, E., & Halliday, A. M. (1980). Components of the movement-related cortical potential and their scalp topography. *Electroencephalography and Clinical Neurophysiology, 49*, 213–226. https://doi.org/10.1016/0013-4694(80)90216-3

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). England: Pearson Education Limited.

Tarkka, I. M., & Hallett, M. (1991). Topography of scalp-recorded motor potentials in human finger movements. *Journal of Clinical Neurophysiology, 8*, 331–341. https://doi.org/10.1097/00004691-199107010-00009

Vaughan, H. G., Costa, L. D., & Ritter, W. (1968). Topography of the human motor potential. *Electroencephalography and Clinical Neurophysiology, 25*, 1–10. https://doi.org/10.1016/0013-4694(68)90080-1

Verleger, R., Grauhan, N., & Śmigasiewicz, K. (2016). Is P3 a strategic or a tactical

component? Relationships of P3 sub-components to response times in oddball tasks with go, no-go and choice responses. *Neuroimage, 143*, 223–234. https://doi.org/10.1016/j.neuroimage.2016.08.049

Verleger, R., Hamann, L. M., Asanowicz, D., & Śmigasiewicz, K. (2015). Testing the S-R link hypothesis of P3b: The oddball effect on S1-evoked P3 gets reduced by increased task relevance of S2. *Biological Psychology,* 108, 25–35. https://doi.org/10.1016/j.biopsycho.2015.02.010

Verleger, R., Jaśkowski, P., & Wascher, E. (2005). Evidence for an integrative role of P3b in linking reaction to perception. *Journal of Psychophysiology, 19*(3), 165–181. https://doi.org/10.1027/0269-8803.19.3.165

Verleger, R., Metzner, M., Ouyang, G., Śmigasiewicz, K., & Zhou, C. (2014). Testing the stimulus-to-response bridging function of the oddball-P3 by delayed response signals and Residue Iteration Decomposition (RIDE). *NeuroImage, 100*, 271–280. https://doi.org/10.1016/j.neuroimage.2014.06.036

Vidal, F., Burle, B., Bonnet, M., Grapperon, J., & Hasbroucq, T. (2003). Error negativity on correct trials: a reexamination of available data. *Biological Psychology*, *64*(3), 265–282. https://doi.org/10.1016/s0301-0511(03)00097-8

Vidal, F., Hasbroucq, T., Grapperon, J., & Bonnet, M. (2000). Is the "error negativity" specific to errors? *Biological Psychology, 51*, 109–128. https://doi.org/10.1016/S0301-0511(99)00032-0

Yeung, N., Botvinick, M. M., & Cohen, J. D. (2004). The neural basis of error detection: Conflict monitoring and the error-related negativity. *Psychological Review, 111*, 931–959. https://doi.org/10.1037/0033-295X.111.4.931

Wessel, J. R. (2018). Prepotent motor activity and inhibitory control demands in different variants of the go/no-go paradigm. *Psychophysiology, 55*(3), Article e12871. https://doi.org/10.1111/psyp.12871

Chapter 4 Supplementary Material

The mean topographies of the unique (i.e., stimulus- or response-specific) and common components are defined statistically in Table S1 and summarised briefly in text. The shorthand indicators describing the statistical topographic effects for the initial components are included in text to aid the reader's interpretation of these outcomes.

Table S1

Stimulus-Specific	N1b			N1c			P2		
Effect	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
F > P	147.92	< .001	.54	5.68	.019	.04			
C > F/P	112.58	< .001	.47	7.09	.009	.05	37.11	< .001	.23
L > R				21.77	< .001	.15			
M > L/R	198.42	< .001	.61	52.09	< .001	.29			
F > P × L > R	3.63	.059	.03	11.08	.001	.08	2.97	.087	.02
F > P × M > L/R	6.88	.010	.05				7.23	.008	.05
C > F/P × L > R				18.10	< .001	.13	4.77	.031	.04
C > F/P × M > L/R	3.75	.055	.03	126.15	< .001	.50	13.41	< .001	.10

Response-Specific	RN2			MP			P420		
Effect	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
F > P	78.14	< .001	.38	100.20	< .001	.44			
C > F/P				25.14	< .001	.17	9.65	.002	.07
L > R	49.39	< .001	.28	6.32	.013	.05			
M > L/R				218.03	< .001	.64			
F > P × L > R	4.05	.046	.03	20.84	< .001	.14	10.51	.002	.08
F > P × M > L/R	22.93	< .001	.16	33.57	< .001	.21	16.72	< .001	.12
C > F/P × L > R	8.46	.004	.06	27.38	< .001	.18	10.75	.001	.08
C > F/P × M > L/R	11.49	.001	.08	134.19	< .001	.52	8.63	.004	.06

Common	P3b			SW1			SW2		
Effect	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
F > P	498.69	< .001	.78	25.93	< .001	.17	34.69	< .001	.22
C > F/P	26.18	< .001	.17	353.41	< .001	.74	48.85	< .001	.28
L > R	22.56	< .001	.15	35.18	< .001	.22	116.85	< .001	.48
M > L/R	2.85	.094	.02	16.75	< .001	.12	4.67	.033	.04
F > P × L > R	62.70	< .001	.33	43.95	< .001	.26			
F > P × M > L/R	135.92	< .001	.52	63.83	< .001	.34			
C > F/P × L > R	34.63	< .001	.22				69.75	< .001	.36
C > F/P × M > L/R									

N.B. F = frontal; C = central; P = parietal; F/P = frontoparietal mean; L = left hemisphere; M = midline; R = right hemisphere; L/R = hemispheric mean. Effects approaching significance are in grey text, and underlined effects are reversed for corresponding underlined results. Two relationship reversals within an effect represents a statistically-equivalent effect (e.g., C < F/P × M < L/R ≡ C > F/P × M > L/R).

N1b was frontocentral (F > P and C > F/P) and dominant in the midline (M > L/R), particularly at frontal sites (F > P × M > L/R). The Go N1c was maximal in the hemispheres (M < L/R), particularly at the temporal sites (C > F/P × M < L/R). Moreover, N1c was larger in the

right hemisphere (L < R) and at frontotemporal sites; these effects also interacted (F > P × L < R and C > F/P × L < R). P2 was maximal at central sites, which were enhanced in the midline (C > F/P × M > L/R) and on the left (C > F/P × L > R). Parietal P2 amplitudes were also greater in the midline, relative to the hemispheres (F < P × M > L/R).

RN2 was maximal at frontal sites and in the right hemisphere; these effects interacted, demonstrating a strong frontal enhancement on the right. Central RN2 amplitudes were also greater on the right and in the midline. The MP was strongly frontal (driving other frontoparietal effects), particularly at the midline and on the left. P420 was enhanced parietally in the midline and right hemisphere, and was reduced centrally, particularly at the midline and in the left hemisphere.

P3b was a large centroparietal positivity that was greater over the right hemisphere, especially at central sites. Parietal P3b amplitudes were also enhanced on the left and at the midline. The positive GM SW1 was maximal at centroparietal sites and strongly dominant in the left hemisphere, particularly at parietal sites. Parietal SW1 amplitudes were also greater in the midline. GM SW2 was strongly negative at parietal, left, and midline sites; this negativity was significantly reduced centrally in the right hemisphere.

Chapter 5. NoGo P3a Cannot Index Response Inhibition: A Single-Trial Latency-Adjusted ERP Analysis

Foreword

This chapter, which investigated the link between the auditory equiprobable NoGo P3a and response inhibition in healthy young adults, is the fourth journal article of this thesis. The lateralised readiness potential (LRP) was used to index prepotent motor activity, and thus, inhibitory demand. The functional significance of NoGo P3a in relation to inhibition was tested by correlating P3a and LRP amplitudes at a single-trial level, after P3a latency jitter was controlled to improve the quantification and measurement of P3a amplitudes. Additionally, source analyses were conducted using eLORETA, to explore the relationship between PCA-derived P3a and known inhibitory control networks in the human brain. The equiprobable NoGo ERP and behavioural data from Experiments 1 and 2 were combined for this investigation, which was submitted for publication.

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (submitted). NoGo P3a cannot index response inhibition: A single-trial latency-adjusted ERP analysis.

Author Contributions

JSF conceptualised this study, and performed the data collection, analyses, and interpretation of the outcomes under the supervision of RJB and GZS. The journal article was drafted and finalised by JSF following critical revisions provided by RJB and GZS. All authors approved the final article prior to submission.

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June 11, 2020	June 11, 2020	June 11, 2020

Abstract

The NoGo P3 event-related potential (ERP) component is often related to response inhibition, although its function in equiprobable Go/NoGo tasks is debated. Previous findings concerning the auditory equiprobable NoGo P3 (i.e., P3a) could be confounded by averaging latency-variable ERP components. This study aimed to control NoGo P3a latency jitter to investigate the component's relationship with inhibitory demands and its neuronal sources across trials. P3a latency jitter was controlled using a novel procedure to enable single-trial P3a quantification across 126 healthy young adults (M_{age} = 20.3, *SD* = 2.8 years) using principal components analysis. NoGo inhibitory demands and performance were measured using the Lateralised Readiness Potential and error rates, respectively. The stimulus-locked P3a (SL-P3a) was also analysed to assess the "blurring effect" associated with ERP averaging. A Spearman's rank correlation across 4,806 NoGo trials demonstrated that the relationship between latency-adjusted P3a (LA-P3a) and inhibitory demands was inconsequential. The cortical sources associated with LA-P3a, using eLORETA, were in the premotor and prefrontal cortices, cingulate, precuneus, and postcentral gyrus. SL-P3a was smaller than LA-P3a, and that difference was positively related to P3a latency jitter; its source solution was also limited to lower activation in the prefrontal cortex. SL-P3a was not related to inhibitory demands or performance. This study demonstrated that NoGo P3a cannot index response inhibition in auditory equiprobable tasks. Instead, the findings support a neuroinhibition account relating P3a to attention. Blurring effects were also shown to impact a standard ERP measure and its source solution, encouraging ERP latency-adjustment in future research.

Keywords: Go/NoGo, P3, Inhibition, Attention, Latency Jitter, eLORETA

1. Introduction

The frontocentral P3 component of the NoGo event-related potential (ERP) is widely considered to reflect response inhibition in Go/NoGo tasks (e.g., Albert et al., 2013; Bokura et al., 2001; Bruin et al., 2001; Dimoska et al., 2006; Falkenstein et al., 2002; Gonzalez-Rosa et al., 2013; Karlin et al., 1970; Pires et al., 2014; Randall & Smith, 2011; Roberts et al., 1994; Smith et al., 2008; Vallesi, 2011). NoGo P3 measures have been used to study inhibitory functioning in clinical populations (e.g., Kamarajan et al., 2005a, 2005b; Ruchsow et al., 2008; Wu et al., 2014; B. Yang et al., 2009; L. Yang et al., 2015), and to evaluate the efficacy of therapeutic approaches addressing cognitive control deficits, such as inattention or impulsivity (e.g., Ogrim & Hestad, 2013; Schoenberg et al., 2014; Yan-ling & Xuan, 2013). However, several theories argue against the inhibition account of NoGo P3 (e.g., Huster et al., 2013; Polich, 2007). Moreover, *equiprobable* Go/NoGo tasks are often used in studies of inhibitory control, even though it is debated whether equiprobable NoGo P3 can index response inhibition (e.g., Wessel, 2018a). In this study, a data-driven approach was used to control NoGo P3 latency jitter and clarify the functional significance of the auditory equiprobable NoGo P3 over individual trials.

1.1. The equiprobable NoGo P3a

Equiprobable Go/NoGo tasks feature an equal number of Go and NoGo trials and are reportedly the most commonly used variant of the Go/NoGo paradigm (Wessel, 2018a). The popularity of this task likely stems from its simplicity and the fact that it is the most efficient variant for acquiring both Go and NoGo data (Barry & De Blasio, 2015; Pfefferbaum et al., 1985). Equiprobable designs are also valuable for studying cognitive processes related to stimulus discrimination and behavioural regulation with minimal (or balanced) Go/NoGo response conflict (Donkers & Van Boxtel, 2004) and oddball deviant effects (Masharipov et al., preprint). Matching Go and NoGo stimulus probability is also believed to moderate the prepotency of the Go response and, relative to that, the NoGo inhibitory demands (Bruin & Wijers, 2002; Low & Miller, 1999; Wessel, 2018a). However, equiprobable tasks could still require effortful inhibition if individuals have a tendency to activate the Go response (Boulinguez et al., 2009; Criaud & Boulinguez, 2013; Donkers & Van Boxtel, 2004).

In simple (i.e., uncued two-stimulus) equiprobable Go/NoGo or oddball tasks, the NoGo P3 is a frontocentral positivity that peaks 250–350 ms after auditory stimuli (e.g., Banquet et al., 1981; Barry & De Blasio, 2013; Griskova-Bulanova et al., 2016; Karamacoska et al., 2017, 2019; Sams et al., 1983) and 300–450 ms after visual and somatosensory stimuli (e.g., Bruin & Wijers, 2002; Di Russo et al., 2000; Gonzalez-Rosa et al., 2013; Iijima et al., 2009; Kiehl et al., 2000; Nakata et al., 2012; Ohbayashi et al., 2017; Piispala et al., 2016, 2017). This positivity is distinct from the centroparietal P300 or P3b (Pfefferbaum et al., 1985; Squires et al., 1975; Dien et al., 2004) and is often referred to as P3a (mostly in the auditory modality), considering its early

latency and the fact that a later P3 can be distinguished (e.g., Barry et al., 2020a; De Blasio & Barry, 2020; Polich, 2007; Squires et al., 1975; Smith et al., 2010).

It has been argued that NoGo P3a and novelty P3 factors seen in different tasks reflect the same component (e.g., Dien et al., 2004; Polich, 2007). This is still debated, and recent evidence indicates that P3a and novelty P3 are distinct frontocentral components (Barry et al., 2020c). Evidence related to ERP measures matching the NoGo P3a in simple equiprobable Go/NoGo (or oddball) tasks is reviewed regardless of the P3 label selected, as the aim of this study was to clarify the functionality of the NoGo P3 in this task. The literature surrounding P3a or novelty P3 in alternate paradigms is not reviewed here explicitly and further consideration of the distinction between those P3 components is beyond this study.

NoGo P3a amplitudes have been shown to increase with stimulus discrimination difficulty (Pfefferbaum et al., 1985) and inter-stimulus-intervals (Recio et al., 2009); as well as decreasing NoGo probability or increasing nontarget-to-nontarget intervals in simple Go/NoGo tasks (Banquet et al., 1981; Bruin & Wijers, 2002; Fogarty et al., 2019; Hull & Harsh, 2001; Keskin-Ergin et al., 2014; Sams et al., 1983; Squires et al., 1975; Wessel, 2018a). A larger equiprobable NoGo P3a is also evident when participants need to pay more attention or activate a motor response to Go stimuli, such as a button-press (Bruin & Wijers, 2002; Falkenstein et al. 1999; Nakata et al., 2008a); although the effect of increasing attention is not always reliable or significant (e.g., Squires et al., 1975; Falkenstein et al. 1999).

Previous EEG and ERP research using equiprobable tasks have shown repeatedly that NoGo P3a is related to EEG delta and theta activity (Barry et al., 2010, 2012, 2014c, 2018b, 2020a; De Blasio & Barry, 2013b, 2018; Spencer & Polich, 1999). Links between NoGo P3a and alpha or beta activity have also been shown, although those findings are less reliable (Barry et al., 2010, 2012, 2014c, 2020a; De Blasio & Barry, 2013a, 2020). Larger NoGo P3a amplitudes have also been related to better behavioural performance in simple equiprobable tasks, as indexed by lower NoGo commission error rates (i.e., false alarm rates), increased Go reaction times, and lower reaction time variability (Fogarty et al., 2018; Karamacoska et al., 2018a, 2018b; Melynyte et al., 2017; Nakata et al., 2012; Nguyen et al., preprint).

Equiprobable NoGo P3a is significantly reduced in individuals with alcohol dependence and the offspring of people addicted to alcohol (Kamarajan et al., 2005a, 2005b), reflecting impaired executive processing consistent with behavioural research in this paradigm (Rupp et al., 2016). A smaller NoGo P3a has also been associated with children who stutter (Piispala et al., 2016, 2017), depression (Zhang et al. 2016), obsessive compulsive disorder (Di Russo et al., 2000), and higher PTSD symptom severity (Wu et al., 2014). Larger NoGo P3a amplitudes are also associated with advancing age (Barry et al., 2014a; Vallesi, 2011; Zhang et al., 2016); with greater anteriorisation (i.e., a more frontal topography) indicated in older adults (Barry et al., 2016a). NoGo P3a latency is also positively related to avoidance (Wu et al., 2014) and heroin

addiction (L. Yang et al., 2015), implying a delay in cognitive processing in individuals with those clinical problems (*cf.* B. Yang et al., 2009).

Previous research suggests that dopaminergic/serotonergic neurotransmitter pathways underpin or influence NoGo P3a generation. Specifically, Melynyte et al. (2017) found that NoGo P3a latencies are greater in females completing an uncued auditory equiprobable task, consistent with the P3a effect of progesterone, a sex hormone that is usually higher in women (Griskova-Bulanova et al., 2016). NoGo P3a amplitudes can also increase after caffeine consumption (Barry et al., 2007, 2020b; *cf.* Barry et al., 2014b, 2019a), during exposure to incense (Iijima et al. 2009), and to white noise (Ohbayashi et al., 2017). Each of these variables are considered to modulate dopamine and/or serotonin activity directly (e.g., progesterone: Dluzen & Ramirez, 1984; caffeine: Volkow et al., 2015; incense: Okugawa et al., 2000; White Noise: Rausch et al., 2014), or indirectly, given the interaction between the dopaminergic and serotonergic neurotransmitter systems at a neurocognitive and behavioural level (see Bethea et al., 2002; Daw et al., 2002; Kapur & Remington, 1996; Kelland & Chiodo, 1996; Seo et al., 2009; Smith et al., 2004; Wong et al., 1995).

Previous ERP source outcomes indicate that uncued auditory equiprobable NoGo P3a represents neuronal activity in the cingulate cortex and cuneus (Barry & Rushby, 2006) or the medial frontal gyrus (Barry et al. 2014a). Using fMRI, Gonzalez-Rosa et al. (2013) associated the visual NoGo P3a with activation in the anterior cingulate and anterior and dorsolateral prefrontal cortices (involving the medial frontal gyrus). This is compatible with other MRI and fNIRS studies in visual and somatosensory modalities, which link equiprobable NoGo processing with activity in the anterior cingulate, dorsolateral and ventrolateral prefrontal cortices, as well as the premotor cortex, insula, inferior frontal gyrus, inferior parietal lobule, temporoparietal junction, and occipito-temporal area (Arbula et al., 2017; Kamarajan et al., 2005b; Laurens et al., 2005; Nakata et al., 2008a, 2008b, 2009; Rubia et al., 2001; Watanabe et al., 2002). Together, these findings indicate a distributed network of brain areas related to equiprobable NoGo processing, although it is difficult to attribute these source outcomes to NoGo P3a *per se*.

The findings associated with the equiprobable NoGo P3a can be interpreted in a number of ways; however, the main theories to be considered are that NoGo P3a reflects *response inhibition* (e.g., Bokura et al., 2001; Fallgatter & Strik, 1999; Karlin et al., 1970; Roberts et al., 1994), NoGo *performance monitoring* (Huster et al., 2020; Liotti et al., 2005; Schmajuk et al., 2006), or alternatively, stimulus-driven *shifts in focal attention* via a neuroinhibitory mechanism (Polich, 2007). This study aimed to test the response inhibition hypothesis for the auditory equiprobable NoGo P3a.

1.1.1. NoGo P3a and response inhibition

Following a similar pattern as equiprobable NoGo P3a amplitudes, inhibitory demands could increase with stimulus discrimination difficulty and Go prepotency (resulting from lower

NoGo probability or increased nontarget-to-nontarget intervals), as the detected stimulus or response conflict requires a higher level of reactive control (Botvinick et al., 2001, 2004; Braver, 2012; Bruin & Wijers, 2002; Chmielewski et al., 2019; Dippel et al., 2016; Low & Miller, 1999; Wessel, 2018a). Larger P3a amplitudes in motor (vs. count) tasks can be explained by increased effort to control overt motor behaviour relative to an implicit decision (Bruin & Wijers, 2002). Moreover, the positive correlation between accuracy and NoGo P3a amplitudes supports a link between NoGo P3a and behavioural control. Response inhibition is also mediated by dopamine (e.g., Albrecht et al., 2014; Beste et al., 2010, 2016; Ghahremani et al., 2012; Nandam et al., 2013; Robertson et al., 2015) and serotonin (e.g., Daly et al., 2014; Humby et al., 2013; Landrø et al., 2015; Macoveanu et al., 2013; Thornton & Goudie, 1978; Ye et al., 2014; *cf.* Clark et al., 2005), as implicated for equiprobable NoGo P3a. Thus, it seems reasonable to consider NoGo P3a as a marker for response inhibition based on these outcomes.

Frontal delta and theta have been linked to executive processing subserving response inhibition (e.g., Adelhöfer & Beste, 2020; Andreu et al., 2019; Harmony, 2013; Harper et al., 2014, 2016; Kamarajan et al., 2004; Kirmizi-Alsan et al., 2006; Müller & Anokhin, 2012; Yamanaka & Yamamoto, 2010); however, it is important to note that delta and theta are implicated in a range of processes (Başar, 1998, 1999; Güntekin & Başar, 2016). Modern accounts of decisional task processing also consider delta to reflect motivated attention and memory (e.g., Knyazev et al., 2007, 2012; Huster et al., 2013), and theta activity to reflect an alerting signal associated with attention and the need for cognitive control (e.g., Başar & Demiralp, 2001; Başar et al., 2001; Brittain & Brown, 2014; Cavanagh & Frank, 2014; Huster et al., 2013; Pscherer et al., 2019). These accounts primarily support links between NoGo P3a and performance monitoring (Huster et al., 2013, 2020; Liotti et al., 2005; Schmajuk et al., 2006) or shifts in focal attention (Polich, 2007), rather than inhibition *per se*.

Neuronal sources associated with equiprobable NoGo P3a (i.e., the anterior cingulate and medial frontal gyrus) have been shown to play a key role in executive functions, including response inhibition (Braver et al., 2001; Gonzalez-Rosa et al., 2013; Rushworth et al., 2004; Talati & Hirsh, 2005). However, these brain areas are also implicated in other control processes, including conflict processing (e.g., Botvinick et al., 1999, 2004; Braver et al., 2001), performance monitoring (e.g., Carter et al., 2001; Ullsperger et al., 2014), and attentional control (e.g., Aarts & Roelofs, 2011; Polich, 2007). The inhibitory control network is also considered to involve the ventrolateral prefrontal cortex (inferior frontal gyrus), as well as the premotor area, and parietal cortex (e.g., Albert et al., 2013; Aron & Poldrack, 2006; Rubia et al., 2001); it is unclear whether NoGo P3a is also related to activity in that inhibitory control neural circuitry and additional research is needed to investigate the sources of P3a in this simple paradigm.

Several studies also contradict the potential relationship between the equiprobable NoGo P3a and response inhibition. Falkenstein et al. (1999) did not find a relationship between NoGo

P3a amplitudes and behavioural control (*cf.* Fogarty et al., 2018; Karamacoska et al. 2018b). Electrodermal studies also indicate that NoGo stimuli are indifferent for young adults in this task, suggesting that equiprobable NoGo stimuli require little to no effortful control, perhaps because the Go response is not predominant (Barry & Rushby, 2006; Recio et al., 2009; Schacht et al., 2009). Indeed, using visual stimuli, Wessel (2018a) demonstrated that only tasks with rare NoGo stimuli show significant levels of prepotent motor activity in NoGo trials. Prepotent motor activity was indexed by the amplitude of the Lateralised Readiness Potential (LRP), a negative scalp potential largest over the motor cortex contralateral to the responding hand, and widely considered to reflect cortical activity associated with the preparation of a voluntary motor response (Coles, 1989; Miller, 1998; Miller & Low, 2001; Smulders et al., 2012). Thus, although inhibition is a reasonable interpretation of the previous NoGo P3a outcomes, it is questionable as to whether this account is plausible in simple equiprobable tasks; further research is needed to relate NoGo P3a to measures of inhibitory demands, as in Wessel (2018a).

1.2. ERP latency variability and adjustment

A potential problem for research measuring NoGo P3a involves ERP latency variability and averaging effects. It is common practice for ERP researchers to average data within subjects and across trials to filter out electrical noise and improve the signal-to-noise ratio of specific ERPs. However, this technique generates within-subject measures that collapse or ignore important variance across trials (Volpert-Esmond et al., 2018; Vossen et al., 2011). This concerns trial-level variance in inhibitory demands, which may fluctuate in latency and magnitude according to the Go/NoGo trial sequence or other factors like practice or time-on-task. Moreover, if the latency of NoGo response processes vary (or jitter) from trial to trial, then any response-related ERP components may be confounded in the averaged stimulus-locked ERP data (McFarland & Cacace, 2004; Truccolo et al., 2002; Spencer, 2005). This is often referred to as a "blurring effect", as latency-variable ERP components are attenuated and smeared in the averaged data, similar to random signal noise (Poli et al., 2010). This unknown level of error can propagate throughout the quantification and analysis of typical stimulus-locked ERP measures of (what is considered to be) implicit NoGo response-related activity, potentially influencing previous study outcomes concerning the functionality of NoGo P3a.

Group or condition differences in P3 latency variability (reflected in the *SD* of P3 peak latencies) could account for significant amplitude effects identified in studies relating NoGo P3a to response inhibition (e.g., Gonzalez-Rosa et al., 2013; Smith et al., 2008; Vallesi, 2011). ERP blurring effects are also expected to be problematic for source localisation, given that averaging can result in the misallocation or 'smearing' of ERP component variance and lower signal-to-noise ratios for latency-variable components in the input ERP data. Indeed, simulations show that overlapping signal noise (or extraneous data) can result in more "ghost sources" and lower precision in ERP source solutions (Grech et al., 2008; Pascual-Marqui, 2002). Thus, it is important

to control or account for ERP latency variability to ensure that amplitude and source localisation outcomes are independent of this potential confound.

In this study, we implement a novel method to control NoGo P3 latency variability in order to investigate NoGo P3a sources and its link to response inhibition at a single-trial level. Controlling ERP component latency jitter typically involves the generation of latency-adjusted ERP data by synchronising (or aligning) epochs to the peak latency of the component in each trial. Several techniques have been developed for that purpose including adaptive filters (Ford et al., 1982; Thornton, 2008; Woody, 1967), template matching (Lange et al., 1997), or maximum likelihood scoring (Tuan et al., 1987). In this study, we applied an iterative P3 peak-detection algorithm to generate latency-adjusted ERPs aligned to the NoGo P3 within participants, before applying temporal principal components analysis (PCA) to extract the single-trial latency-adjusted P3a (LA-P3a). This simple approach was designed specifically for this study to control P3 latency variability and extract trial-level P3a variance for analysis.

Similar approaches have been implemented previously to study P3. For example, Pfefferbaum et al. (1985) applied PCA to latency-adjusted ERPs averaged within participants, after using Woody's (1967) filter to synchronise ERP data to the P3 across trials. Saville et al. (2011) used PCA to extract P3 from stimulus-locked ERP data averaged within subjects, and then applied that factor to individual trials to measure and control for P3 latency jitter. Independent Components Analysis (ICA) has also been used to quantify single-trial ERP data through the back-projection of ICA components identified within participants (Wessel, 2018a, 2018b; Debener et al., 2005); however, temporal ICA (and PCA) solutions are also influenced by ERP latency jitter (see Möcks, 1986). To the best of our knowledge, no study has applied factor analysis or blind signal separation directly to *single trial* ERP data *after* P3 latency jitter has been controlled within and between participants.

1.3. The present study

Previous equiprobable NoGo P3a outcomes may be explained by theories relating NoGo P3 (or P3a) to inhibition, monitoring, or attention. This study aimed to test the response inhibition hypothesis of the equiprobable NoGo P3a in the *auditory* modality. Following Wessel (2018a), LRP was calculated in NoGo trials to correlate P3 with inhibitory demands. NoGo P3 amplitudes reflecting larger inhibitory demands were expected to increase with the magnitude of negative LRP amplitudes. A novel method was also used to control ERP latency variability and quantify single-trial P3a in a large sample of healthy young adults, providing substantial statistical power, to investigate behavioural and neuronal correlates of the auditory equiprobable NoGo P3. The cortical sources of the LA-P3a were also explored to clarify the factor's neuronal origin without the influence of ERP blurring effects.

Similar analyses were conducted on the averaged stimulus-locked P3a (SL-P3a) to provide a 'standard' reference for the LA-P3a and assess the impact that latency jitter can have

on typical P3 measures. SL-P3a was also examined in relation to performance to replicate previous outcomes (Fogarty et al., 2018; Karamacoska et al., 2018b). Due to the blurring effect (Poli et al., 2010), SL-P3a was expected to be smaller than LA-P3a averaged within participants (i.e., at the participant level). No predictions were made regarding the differences in SL-P3a and LA-P3a sources, although SL-P3a was expected to be related to activation in the cingulate, cuneus, and medial frontal gyrus.

The purpose of this investigation was to clarify the functionality of the equiprobable NoGo P3a and determine whether it can be considered a potential marker of response inhibition. This was considered important given that equiprobable tasks are reported to be the most commonly used Go/NoGo variant. This paradigm is also frequently used to study or assess inhibitory control in a range of fundamental and clinical research areas; hence, the outcomes of this study were expected to clarify the functionality of the NoGo P3a as well as the utility of the simple equiprobable task.

2. Method

2.1. Participant demographics and screening

NoGo ERP data from 126 healthy right-handed young adults (M_{age} = 20.3, SD = 2.8 years, 83 female) were collated from the two independent samples published in Fogarty et al. (2019, 2020) to substantially increase N for statistical analysis; the NoGo P3 has been examined in only one of these datasets (in relation to stimulus probability: Fogarty et al., 2019). Participants were psychology students at the University of Wollongong who volunteered to participate for course credit through the School of Psychology Research Participation Scheme. Participants provided their informed consent before screening and testing. Screening was conducted via self-report questionnaires: volunteers were excluded from testing if they reported ongoing mental illness (e.g., depression) or neurological complaints (e.g., epilepsy), previous head injuries (e.g., concussion), were not right-handed (according to the Edinburgh Handedness Inventory; Oldfield, 1971), or had consumed tobacco/caffeine (≤ 4 hours) or other psychoactive substances (≤ 12 hours) before testing. This study was approved by the University of Wollongong and Illawarra Shoalhaven Local Health District Human Research Ethics Committee (HE09/220).

2.2. Physiological recording

A Neuroscan SynAmps2 amplifier was used to record continuous electrophysiological data at 1000 Hz between 0–30 Hz from 30 EEG scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2), the right mastoid (M2), and four EOG sites located above and below the left eye, and beside the outer canthus of each eye. Each electrode was referenced to the left mastoid (M1), and grounded at AFz, and all were sintered Ag/AgCl with impedances below 5 kΩ.

2.3. Go/NoGo task and procedure

Participants were seated in a dark sound-attenuated room to complete Croft and Barry's (2000) EOG calibration task, and an auditory equiprobable Go/NoGo task (i.e., p_{NoGo} = .5). The Go/NoGo task featured two blocks of 150 randomly shuffled 1000 and 1500 Hz tones, presented through circumaural headphones for 80 ms (including 15 ms rise/fall times), using a fixed SOA of 1250 ms. Tone intensity was calibrated at 60 dB SPL at the headphone using an artificial ear and sound level meter (Brüel & Kjær, model 4152).

Participants were instructed to respond to Go tones as quickly and accurately as possible with a button-press from their right hand, while keeping their gaze on a white fixation cross projected onto the wall in front of them throughout the task. An example of the Go tone and a short practice (10 trials) were provided prior to each block. Go tone frequency and block order were counterbalanced across blocks and participants, respectively.

2.4. Data quantification and analysis

NoGo accuracy was measured within-subjects using the NoGo commission error rate (i.e., the % of NoGo trials that were incorrectly responded to with a button-press). All EEG data were EOG corrected using the RAAA procedure (Croft & Barry, 2000) and re-referenced to digitally linked mastoids in Neuroscan Edit (Compumedics v. 4.5). LRP data were then generated as the difference between the C3 and C4 EEG electrode data (i.e., C3 minus C4) and then low-pass filtered (FIR 4 Hz, 24 dB/Octave, zero-phase shift) to help isolate LRP slow-wave data (Coles, 1989; Smulders et al., 2012; Wright et al., 2011). Separate to that, the re-referenced EEG data at all 30 channels were low-pass filtered to 25 Hz (FIR, 24 dB/Octave, zero-phase shift) following our standard filtering procedure (e.g., Fogarty et al., 2019).

LRP data were epoched ±500 ms around the intra-subject mean Go RT in each NoGo trial, following Wessel (2018a), whereas the EEG data were epoched from -400 to +1250 ms around NoGo stimulus onset. The NoGo LRP and ERP data in each trial were baselined to the 100 ms directly preceding stimulus onset, and epochs containing artefact exceeding ± 100 μV were removed across both the LRP and ERP datasets to ensure that the NoGo LRP and ERP trial datasets were comparable within subjects. The remaining artefact free ERP trials were used to generate stimulus-locked and latency-adjusted ERP data for further analysis.

2.4.1. Averaged stimulus-locked ERP data

Correct and incorrect (i.e., error-related) NoGo stimulus-locked ERP averages were computed within-subjects and truncated to -100 to +750 ms around stimulus onset. The correct NoGo ERP data were then decomposed using temporal PCA. The PCA was conducted in Matlab (The Mathworks, v. 8.0, R2012b) using functions provided by Kayser and Tenke (2003) (http://bit.ly/2oX0etA), which were modified to avoid removal of the grand mean (GM) ERP from each case (Barry et al., 2016b; Dien & Frishkoff, 2005). The covariance matrix was used, with Kaiser normalisation, and all components were Varimax rotated to maintain factor orthogonality.

There were 3,780 cases (126 participants × 30 sites) and 850 components (time points), leading to a case to component ratio of 4.45 to 1. Factors explaining ≥ 5 % of unique ERP variance were extracted, and their identification was guided by their temporal and topographic features output by the PCA.

2.4.2. Latency-adjusted ERP data

Latency-adjusted NoGo ERP data were computed *within-subjects* in Matlab using a data-driven procedure designed to minimise P3 latency jitter. Figure 1 illustrates the processing stages involved in that procedure as it was applied to ERP data from participant #1. For each participant, **(Step 1)** individual NoGo P3 peak latencies were estimated in correct trials by identifying the largest positive peak between 0–750 ms poststimulus at FCz[2]. **(Step 2)** A P3 time window was then calculated for the participant as the period between ±1 *SD* of their initial mean P3 peak latency across trials. **(Step 3)** Final estimates of the individual's intra-trial P3 peak latencies were then calculated using the largest positive peak in their P3 time window in each trial. **(Step 4)** NoGo trials with invalid P3 estimates were rejected: invalid trials included P3 peak amplitudes that were negative or not technically a peak (i.e., it was not the largest positivity in the period ±5 ms around the estimated latency). **(Step 5)** The remaining data were then epoched ±425 ms around the final P3 latency estimate in each trial, effectively aligning the P3 peak across trials and participants at time zero.

The PCA approach in Method section 2.4.1 was used to quantify the LA-P3a at the individual trial level. Eighty latency-adjusted trials were randomly selected from each participant for the PCA, as this was the maximum that could be selected while maintaining a consistent amount of input from each individual. The PCA input was also restricted to ±1 *SD* of the mean intra-subject P3 peak latencies (rounded up to the nearest integer) around zero, which was 0 ± 45 ms (i.e., 90 data points). This was to focus the PCA on the P3 waveform and minimise the likelihood that other extraneous latency-variable components would confound the quantification of P3a during the factor rotation stage (see Harshman et al., 2003). Thus, the latency-adjusted PCA involved 302,400 cases (126 participants × 30 sites × 80 trials) and 90 components, resulting in a case to component ratio of 3,360 to 1. The aim of this PCA was to quantify LA-P3a at each trial, hence, only the component explaining the most variance was retained for analysis.

[2] FCz was chosen as it was the peak site of the grand mean stimulus-locked P3a in this study.

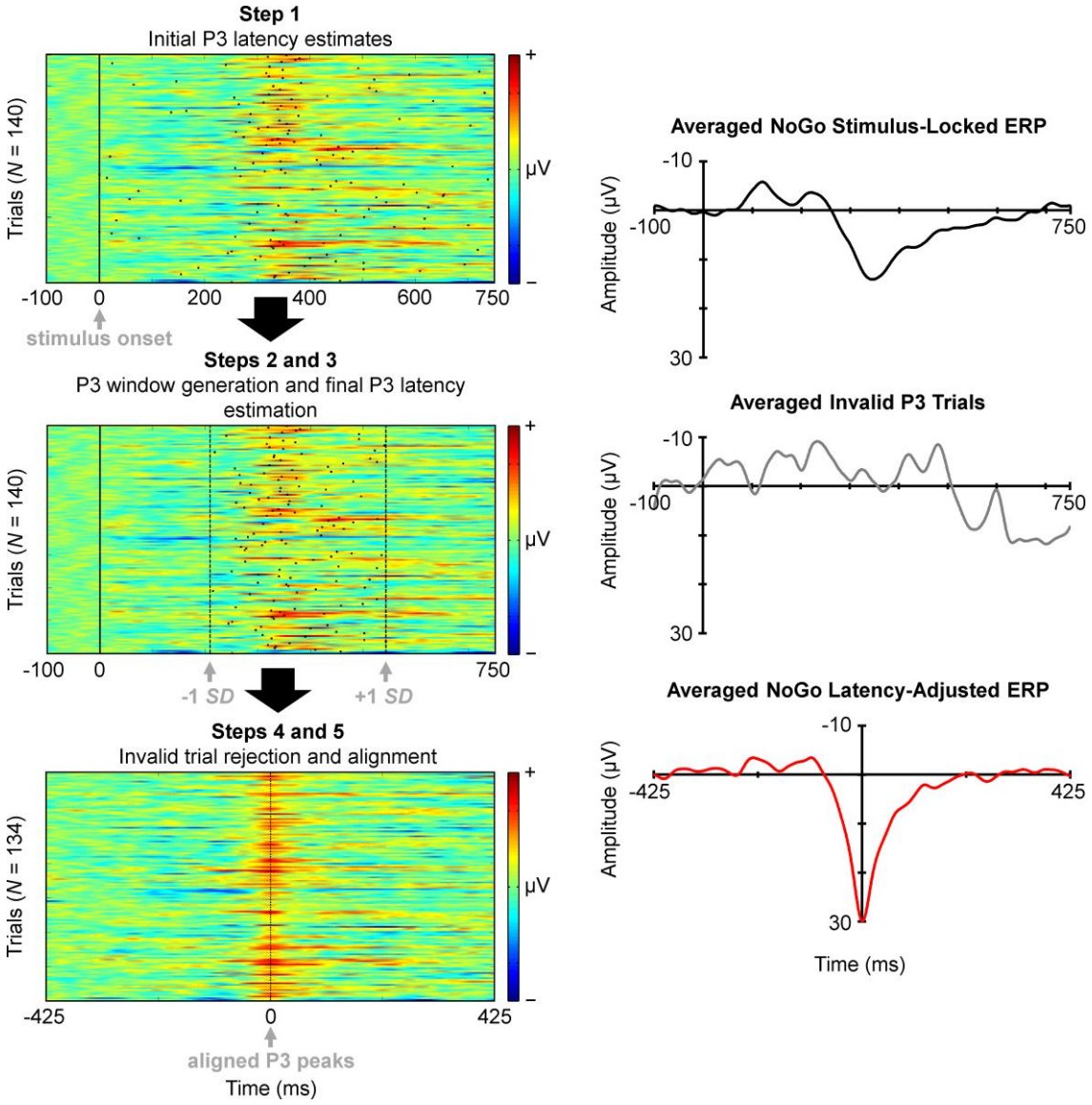


Figure 1. Left: The latency adjustment procedure (Steps 1–5) demonstrated using single-trial NoGo ERP data from participant #1. Black dots reflect the estimated intra-trial P3 peak latencies, and the dashed lines in Step 2 reflect the range of the participant's P3 time window (±1 SD around the mean of the estimated latencies in Step 1). Right: The original stimulus-locked, invalid, and latency-adjusted ERPs averaged across trials at FCz for participant #1.

2.4.3. P3a and LRP measurement

Subject- and trial-level P3a amplitudes were measured from the SL-P3a and LA-P3a (PCA) component waveforms[3], respectively, using the average amplitude over FCz and Cz at the component's peak latency. FCz and Cz were the peak scalp sites of P3a and using the average between the two locations was considered to minimise the effect of any potential error at any one

[3] PCA component waveforms (scaled to microvolts) are computed by multiplying each factor loading by the factor scores and the standard deviations from the input data (see Dien & Frishkoff, 2005).

site (Barry & De Blasio, 2015). The difference between SL-P3a and LA-P3a amplitudes (averaged across trials and within subjects) was calculated for each participant to examine the change in P3a amplitude related to the blurring effect. P3a latency jitter was measured within subjects as the standard deviation of P3a's peak latency in the eighty LA-P3a trials selected for analysis.

NoGo LRP amplitudes were measured in each trial using the mean across the 500 ms period preceding the individual's mean Go RT (Wessel, 2018a). Only negative LRPs were considered to index prepotent motor activation of the Go response (i.e., trials with positive LRP amplitudes were excluded), given that positive LRP amplitudes can reflect alternate motor responses (Coles, 1989). Prepotent motor activation (negative LRP) was computed separately for analysis with SL-P3a and LA-P3a; within each dataset, the same trials were used to calculate the prepotent motor activity and P3a amplitudes for correlations.

2.4.4. Statistical analyses

A Pearson's correlation between the GM SL-P3a and LA-P3a peak topographies over all 30 EEG scalp sites was used to assess the similarity of the two P3a components. To examine the blurring effect, a two-way repeated measures *t*-test was used to analyse the difference between SL-P3a and LA-P3a peak amplitudes, and a simple correlation was computed between P3a latency jitter and the change in SL-P3a and LA-P3a amplitudes. To account for the large variability in the ERP and behavioural data, Spearman's rank correlations were used to evaluate the relationship between SL-P3a, error rates, and LRP amplitudes at the participant-level, and between LA-P3a amplitudes and LRP amplitudes at the trial level.

To clarify the neuronal generators underpinning NoGo P3a, the cortical sources of the SL-P3a and LA-P3a PCA component waveforms were estimated using exact low-resolution electromagnetic tomography (eLORETA) in LORETA-KEY (v. 20170220; Pascual-Marqui, 2007, 2009). eLORETA separates the brain volume into 6239 cortical voxels of 5 mm^3 and exports 3-D linear inverse solution locations relative to a realistic brain atlas from the Montreal Neurological Institute (MNI152 2009c); voxel (source) activation is reflected in the magnitude of the estimated current density ($\mu A/mm^2$) (Anderer & Saletu, 2013).

Following Barry et al. (2020c) and Fogarty et al. (2020), default settings were used in LORETA-KEY to export both positive and negative data, with no regularisation, and a threshold of 0.0000001 to yield 100 % of the voxel data. The output voxel data were grouped by their structural brain location. Current densities were summed to identify the most active structures explaining ≥ 50 % of the total current density for the P3a components; these are reported in the results, along with the Brodmann Areas (BAs) that accounted for ≥ 90 % of the activation in those selected structures.

3. Results

3.1. Raw ERP and trial data

Figure 2 presents the GM raw ERPs (Left) and a comparison of correct and incorrect stimulus-locked ERP data (Right). Across the entire sample, the average NoGo commission error rate was 3.0 (*SD* = 2.6) %. There was an average of 140.5 (*SD* = 9.4) stimulus-locked NoGo trials remaining per participant following error and artefact rejection. From those data, an average of 128.9 (*SD* = 8.8) trials were accepted following the P3 latency-adjustment procedure, from which eighty trials per participant were randomly selected for further analysis.

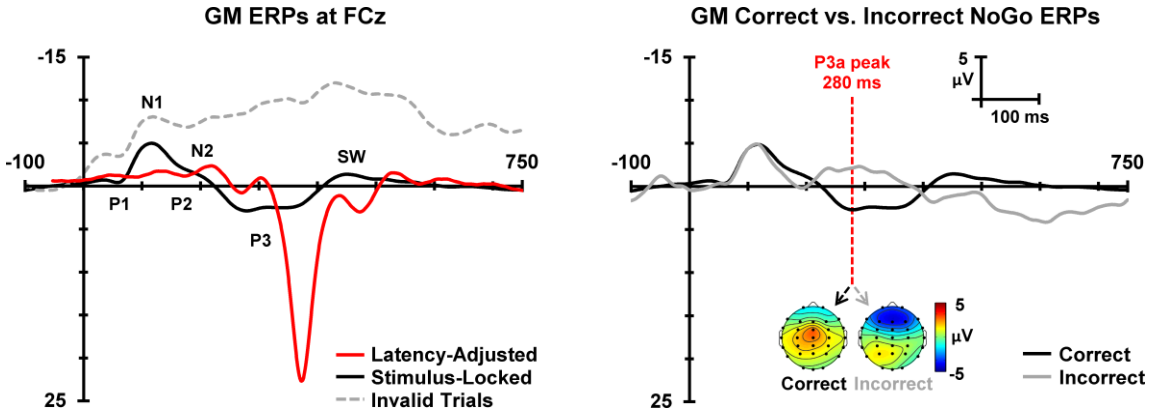


Figure 2. Left: GM raw ERPs computed from correct stimulus-locked, latency-adjusted, and invalid trial data at FCz. The latency-adjusted data are centred at the GM P3a peak latency, 371.8 (SD = 44.5) ms. Right: A comparison of GM correct and incorrect ERPs at FCz across the participants who made errors. Correct and incorrect headmaps were both generated at the peak latency of the raw GM P3 in this subsample.

ERP data from 114 participants were used to generate the GM correct and incorrect NoGo stimulus-locked ERPs for visual comparison in Figure 2 (12 participants made no commission errors and were excluded). P3a can be observed ~ 280 ms poststimulus in the correct ERP, but no P3a is evident in the incorrect ERP; in its place is a prominent frontal error-related negativity. No statistical tests were conducted using incorrect ERP data due to the limited number of error trials available for averaging per participant (*M* = 5.0, *SD* = 3.7 error trials, *n* = 114).

Figure 3 depicts the GM NoGo LRP difference waveform and a scatter plot illustrating the averaged NoGo LRP amplitudes calculated relative to the mean Go RT within subjects. The GM difference waveform was positive in the pre-response period, suggesting that prepotent motor activity was not evident across subjects in this study; this is supported in the scatter plot, which showed that mean LRP amplitudes were mostly positive. However, prepotent motor activity (negative LRPs) was evident in a small subsample of participants (*n* = 31).

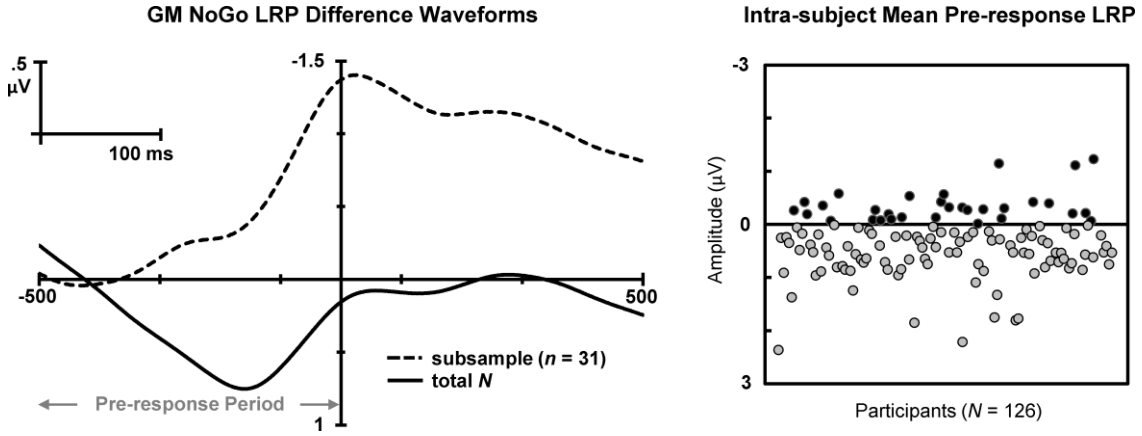
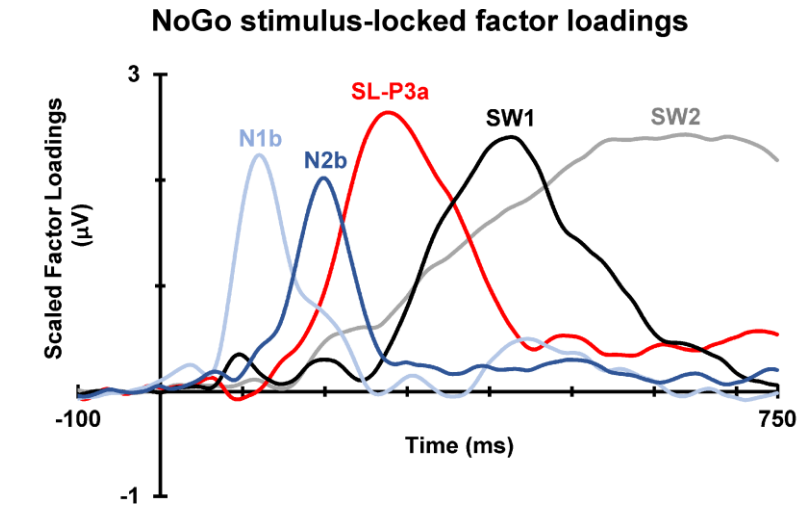


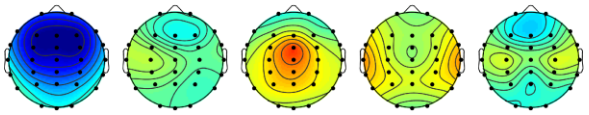
Figure 3. Left: GM NoGo LRP difference waveforms averaged across the entire sample in this study and the subsample with negative pre-response LRP amplitudes. Right: Mean pre-response LRP amplitudes computed within-subjects; grey and black markers distinguish positive and negative LRP amplitudes, respectively.

3.2. Averaged SL-P3a outcomes

Figure 4 shows the averaged stimulus-locked ERP components extracted using temporal PCA. Five components were output from the correct NoGo stimulus-locked ERP data, including N1b, N2b, P3a, and slow-wave components (SW1 and SW2), explaining a combined total of 87.1 % of the ERP variance. Spearman's rank-order correlations showed no significant relationship between SL-P3a amplitudes (M = 2.95, SD = 4.01 µV) and NoGo error rates, $r_s(124) = -0.10$, p = .286. Likewise, no relationship was found between the NoGo SL-P3a (M = 3.01, SD = 4.40 µV) and LRP amplitudes (M = -0.35, SD = 0.31 µV) in the subsample of individuals showing prepotent motor activity, $r_s(29) = -0.03$, p = .866. These findings indicate that typical SL-P3a amplitudes are not related to behavioural performance or inhibitory demands at the participant-level.



NoGo PCA headmaps and factor information



Label	N1b	N2b	**SL-P3a**	SW1	SW2	
Factor	4	5	**2**	3	1	#
Latency	120	198	**277**	426	638	ms
Variance	6.5	5.4	**18.6**	17.8	38.8	%

Figure 4. The five PCA components extracted from the averaged NoGo stimulus-locked ERP data, including their scaled factor loadings (top), and their unique headmaps and factor information (bottom).

3.3. LA-P3a outcomes

Figure 5 depicts the LA-P3a extracted from single trial ERP data using temporal PCA (Panel A), and the influence of P3a latency jitter on P3a amplitudes (Panel B) and cortical sources (Panel C). NoGo LA-P3a was extracted as Factor 1 and explained 40.4 % of the latency-adjusted ERP variance. The topography of the LA-P3a was highly correlated with that of the stimulus-locked component, $r(28) = 0.63$, $p < .001$, indicating that a comparable P3a component was extracted across trials after controlling for P3a latency jitter. As expected, the repeated measures *t*-test showed that SL-P3a ($M = 3.0$, $SD = 4.0$ µV) was significantly smaller than LA-P3a ($M = 21.6$, $SD = 6.6$ µV) at the participant-level; $t(125) = -30.9$, $p < .001$. Moreover, as illustrated in Figure 5B, there was a significant positive correlation between P3a latency jitter ($M = 120.4$, $SD = 21.2$ ms) and the magnitude of that difference ($M = 18.6$, $SD = 6.8$ µV), $r(124) = .42$, $p < .001$, demonstrating that P3a latency jitter accounted for a moderate amount of the blurring effect on SL-P3a amplitudes.

From the 10,080 NoGo trials that were measured across participants, only 4,806 featured prepotent motor activity and were analysed in relation to the LA-P3a amplitudes in those same trials. Spearman's rank-order correlation showed a small, but significant, negative relationship

between NoGo P3a and LRP amplitudes at the trial level, $r_s(4,804) = -0.12$, $p < .001$. However, the statistical significance of that small correlation likely reflects the large number of trials. According to this result, prepotent motor activity accounted for 1.4 % of the variance in LA-P3a amplitudes, which is considered to be inconsequential.

Panel C in Figure 5 compares the SL-P3a and LA-P3a source outcomes. SL-P3a was associated with activation in the superior frontal gyrus, middle frontal gyrus, and medial frontal gyrus. Four BAs explained 94.1 % of the activation in those structures, including in order of their intensity, BAs 6, 8, 9, and 10. In contrast, the LA-P3a was associated with additional sources and greater cortical activation (see the right of Figure 5, Panel C). In order of their intensity, LA-P3a was related to activation in the cingulate gyrus, superior frontal gyrus, middle frontal gyrus, medial frontal gyrus, precuneus, and postcentral gyrus. Ten BAs accounted for 93.6 % of the activation in those structures, including BAs 6, 8, 7, 24, 9, 31, 32, and 10.

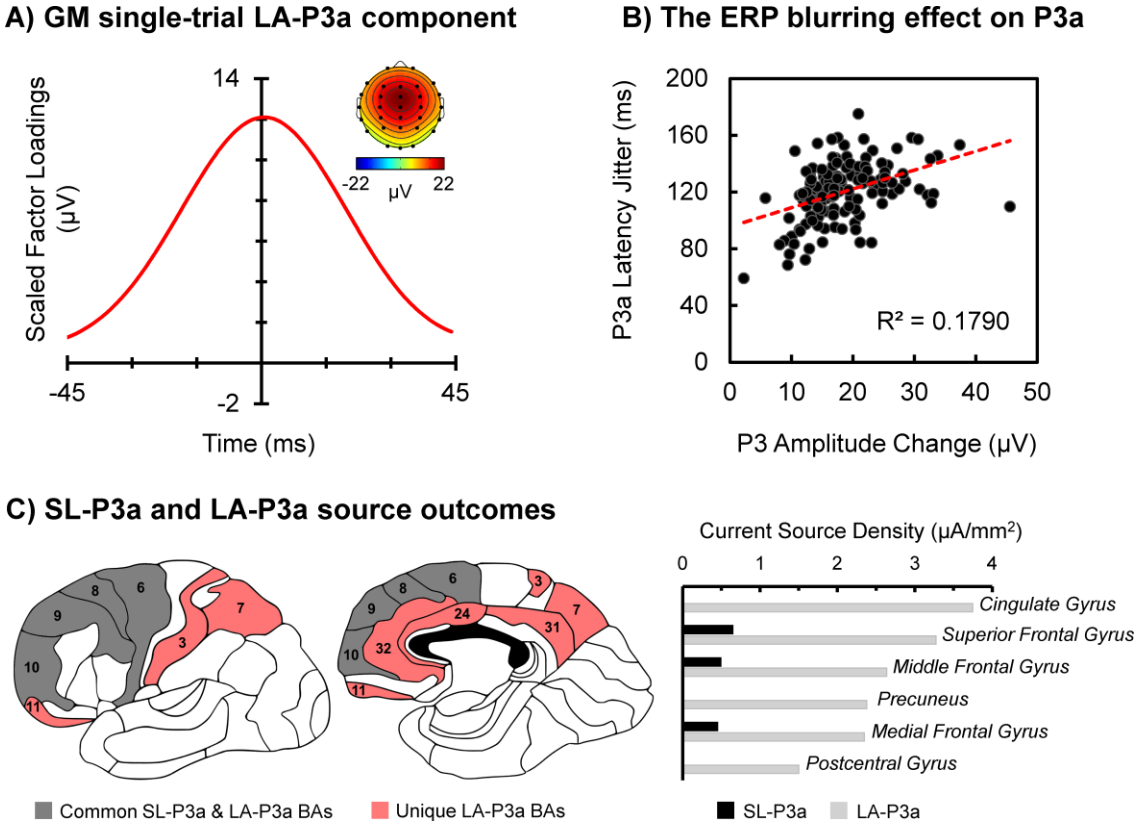


Figure 5. Panel A: The GM LA-P3a extracted across 10,080 correct artefact-free NoGo trials; the PCA component's peak topography is plotted next to its scaled factor loading. Panel B: The positive relationship between P3a latency jitter and the change in P3a amplitudes after controlling latency jitter. Panel C: A comparison of the most active cortical sources associated with SL-P3a and LA-P3a. The most active BAs are illustrated on the left and the total current source density (CSD) across all BAs in each active cortical structure is plotted on the right.

4. Discussion

This study aimed to clarify the functional significance of the NoGo P3a in the auditory equiprobable Go/NoGo task, with a focus on the component's potential relationship with response inhibition. The latency-adjustment procedure in this study controlled NoGo P3a latency jitter within participants, enabling the extraction and analysis of NoGo P3a data at the trial level, without ERP averaging. As expected, increased P3a latency jitter was shown to have a greater 'blurring effect' on averaged SL-P3a amplitudes, impacting the source solution computed using eLORETA. The relationship between single-trial LA-P3a and LRP amplitudes was also remarkably trivial, and SL-P3a was not related to performance or LRP amplitudes at the participant level, indicating that NoGo P3a cannot effectively index response inhibition in this paradigm. The present study outcomes provide insight into the functional significance of equiprobable NoGo P3a, which could reflect an internally-directed shift in attention.

4.1. P3 latency adjustment

Latency-adjusted NoGo ERP data were generated in this study to control P3a latency jitter within and between participants. Correct NoGo trials that did not feature a P3a (i.e., invalid trials) were also identified and excluded from analysis. This approach was expected to reduce the blurring effect associated with averaging latency-variable components (see Poli et al., 2010), and to minimise the impact of irrelevant ERP data, which could confound P3a quantification using typical stimulus-locked measures.

Topographically, the P3a extracted from the stimulus-locked and latency-adjusted ERP data were highly similar. However, as expected, SL-P3a amplitudes were significantly smaller relative to the LA-P3a, and this was predicted by the amount of P3a latency jitter measured within-subjects (Trongnetrpunya et al., 2019; Spencer et al., 2000; Walhovd et al., 2008). The LA-P3a positive waveform deflection was also much 'sharper' in its morphology than the SL-P3a, indicating that there was less smearing of the P3a in the averaged latency-adjusted ERP data. Together, these findings demonstrate the negative impact that latency jitter can have on typical ERP component measures, and the potential value of latency jitter correction in ERP research (Picton et al., 2000; Luck, 2005; Poli et al., 2010; Spencer, 2005).

4.2. P3, LRP, and behaviour

NoGo P3a in this study was a frontocentral positivity that peaked 277 ms poststimulus, similar to the NoGo P3a in prior research using auditory (e.g., Banquet et al., 1981; Barry & De Blasio, 2013; Borchard et al., 2015; Fogarty et al., 2018, 2019; Griskova-Bulanova et al., 2016; De Blasio & Barry, 2013a, 2013b, 2018, 2020; Karamacoska et al., 2017, 2018a, 2018b, 2019; Melynyte et al., 2017; Sams et al., 1983; Squires et al., 1975), visual (e.g., Bruin & Wijers, 2002; Di Russo et al., 2000; Gonzalez-Rosa et al., 2013; Iijima et al., 2009; Kamarajan et al., 2005a; Piispala et al., 2016), or somatosensory stimuli in this paradigm (Nakata et al., 2012; Ohbayashi et al., 2017); although NoGo P3a has a later peak after visual or somatosensory stimuli.

SL-P3a reflects a typical stimulus-locked quantification of NoGo P3a in the simple auditory equiprobable Go/NoGo task and features negative scalp amplitudes at the most anterior sites, which is evident in previous studies that illustrate NoGo P3a topography across the entire scalp (e.g., Borchard et al., 2015; Bruin & Wijers, 2002; Fogarty et al., 2018, 2019; Wu et al., 2014; Zhang et al., 2016). This frontopolar negativity is not apparent in the LA-P3a topography suggesting that it is not synchronised with frontocentral P3a amplitudes and, thus, likely reflects overlapping activity from other frontally negative components (e.g., N2b, SW2).

The GM NoGo LRP waveforms were positive in this study, indicating that, on average, healthy young adults did not exhibit prepotent motor activity in the uncued auditory equiprobable Go/NoGo task, consistent with results in the visual modality (Wessel, 2018a). This indicates that, overall, healthy young adults do not have a tendency towards the Go response in this task (Donkers & Van Boxtel, 2004). More importantly, this finding corroborates research suggesting that, in general, equiprobable tasks do not require effortful inhibition in NoGo trials (Barry & Rushby, 2006; Recio et al., 2009; Schacht et al., 2009; Wessel, 2018a). Together with those previous studies, the current results show that simple equiprobable Go/NoGo tasks are not suitable for studying response inhibition in healthy adults *per se*. Nevertheless, prepotent motor activity was reflected in subsamples of the LRP data in this study, indicating that inhibitory demands occur in certain individuals and some NoGo trials in this task.

A negative relationship was found between LA-P3 and LRP amplitudes over the NoGo trials that showed prepotent motor activity. However, LRP explained only 1.4 % of the variance in NoGo P3a amplitudes, and the statistical significance of that correlation is thought to reflect the massive statistical power at the trial level (similar to Type I error), rather than being of any practical significance. No relationship was identified at the subject level between SL-P3a and LRP, with the smaller *N* yielding lower power that is perhaps more typical of ERP studies. Thus, while there was a minor correlation at the trial level, the present outcomes indicate that there is no meaningful relationship between NoGo P3a amplitudes and response inhibition in simple auditory equiprobable tasks.

No significant correlation was found between SL-P3a amplitudes and error rates. P3a was also absent in a number of correct NoGo trials. This does not mean that P3a is not related to successful NoGo processing, especially considering that incorrect NoGo trials were associated with a prominent frontal error-related negativity instead of P3a (see Figure 2). However, together, these findings show that P3a does not effectively predict NoGo performance in healthy young adults (Falkenstein et al., 1999; *cf.* Fogarty et al., 2018; Karamacoska et al., 2018b). That is, according to the LRP and behavioural outcomes in this study, NoGo P3a cannot be used to index successful response inhibition or behavioural accuracy in simple equiprobable tasks.

4.3. NoGo P3a sources

The LA-P3a was related to cortical activation in the frontal and parietal lobes, including the premotor cortex (BA 6), dorsolateral and orbitofrontal prefrontal cortex (BAs 8, 9, 10, and 11), anterior and posterior cingulate (BAs 24, 31, and 32), precuneus (BA 7), and postcentral gyrus (i.e., the primary somatosensory cortex: BA 3). Relative to that, SL-P3 was associated with less activation in the frontal lobe (in BAs 6, 8, 9, and 10) and activity in the orbitofrontal cortex, cingulate, precuneus, or postcentral gyrus was not prominent. The differences between these outcomes shows that ERP latency jitter can impact the source solution of averaged ERP data. However, the topography of the LA-P3a and SL-P3a were highly similar and there were no unique sources in the typical stimulus-locked solution; this indicates that latency jitter did not result in erroneous 'ghost sources' (at least, not above threshold; see Method 2.4.4.), rather, these outcomes likely reflect differences in P3a amplitude or signal-to-noise ratio. In this case, the attenuation of SL-P3a due to the blurring effect (averaging latency variable data) could explain the limited SL-P3a source solution relative to LA-P3a.

The LA-P3a source outcomes in this study corroborate prior research linking auditory equiprobable NoGo P3a to activation in frontal and parietal brain regions, particularly in the cingulate cortex and medial frontal gyrus (Barry et al., 2014a; Barry & Rushby, 2006). These findings are largely consistent with P3a sources identified in similar tasks (e.g., Go/NoGo, oddball and habituation tasks) using a variety of ERP measurement and source localisation techniques (e.g., Bachiller et al., 2018; Barry et al., 2020c; Bokura et al., 2001; Kamarajan et al., 2005b; Takahashi et al., 2013; Volpe et al., 2007; Wronka et al., 2012).

fMRI research in the visual modality supports the connection of the cingulate and medial frontal gyrus to equiprobable NoGo P3a (Gonzalez-Rosa et al., 2013). Studies using MRI and fNIRS have also shown that equiprobable NoGo processing is linked to a distributed network including the cingulate, prefrontal cortices, premotor cortex, insula, inferior parietal lobule, temporoparietal junction, and occipito-temporal area (Arbula et al., 2017; Kamarajan et al., 2005b; Laurens et al., 2005; Nakata et al., 2008a, 2008b, 2009; Rubia et al., 2001; Watanabe et al., 2002). The present findings support the involvement of a distributed network in auditory NoGo processing and suggest that NoGo P3a can account for activity in a number of these areas, including the cingulate, prefrontal cortices, and premotor cortex. Additional P3a sources identified here may also reflect close approximations of activity identified with MRI (e.g., the cuneus vs. inferior parietal activity). The distributed sources here could also reflect the LORETA method, which estimates solutions over the entire cortex, and is known to have lower spatial resolution than other dipolar methods (for useful reviews, see Anderer & Saletu, 2013; Grech et al., 2008; He & Ding, 2013; Michel et al., 2004; Yao & Dewald, 2005). However, using the eLORETA solution was considered a strength of this study, as it makes no assumptions about the source distribution, and it is robust against noise and more accurate at greater depths relative to

other localisation methods (Halder et al., 2019; Jatoi et al., 2014; Pascual-Marqui, 1999, 2002). The overlap of the present findings with previous ERP and MRI research also shows that the current outcomes are reasonable, although simultaneous EEG and MRI research in this auditory task would be useful to clarify the results.

A brief overview of the major cognitive functions associated with the LA-P3a sources is provided here for consideration. Activity in the premotor cortex is broadly related to motor planning (e.g., Catalan et al., 1998; Purves et al., 2001; Shubotz & von Cramon, 2002), whereas activation in the prefrontal cortex is associated with a range of executive functions including working memory, decision making, the control of attention and behaviour (Blumenfeld & Ranganath, 2007; Hoshi, 2006; Knight et al., 1995; Lara & Wallis, 2015; Miller & Cohen, 2001). The anterior cingulate is linked to similar functions, although it has primarily been associated with control processes such as conflict monitoring and inhibition (Botvinick et al., 2001, 2004; Braver et al., 2001; Gonzalez-Rosa et al., 2013; Peterson et al., 1999, 2002; Rushworth et al., 2004; Talati & Hirsh, 2005; Woodward et al., 2006). The postcentral gyrus is related to sensory (particularly somatic) processing and proprioception (DiGuiseppi & Tadi, 2019), and both the posterior cingulate and precuneus have been related to internally directed attention and prospective and retrospective memory (see Cavanna & Trimble, 2006; Leech & Sharp, 2014).

4.4. Functional implications for equiprobable NoGo P3

The observations in this study have several functional implications for the NoGo P3a in the auditory equiprobable Go/NoGo task. **(1)** P3a does not appear to occur in incorrect NoGo trials, suggesting that it is associated with successful NoGo processing. However, **(2)** P3a is not evident in every correct NoGo trial (i.e., invalid trials), implying that successful NoGo processing is not always dependent on the cortical processes underpinning P3a. This suggests that P3a reflects an active process, rather than an automatic stimulus-driven response (*cf.* Muller-Gass et al., 2007). **(3)** Motor response inhibition does not account for P3a, given the relatively-trivial link between P3a and prepotent motor activity in this study. However, **(4)** many of the cortical sources underpinning P3a are related to inhibitory control (e.g., Albert et al., 2013; Aron & Poldrack, 2006; Rubia et al., 2001). **(5)** The LA-P3a source outcomes imply a link between P3a and sensory and motor processing, memory, cognitive control, and attention (towards the self).

These findings can be interpreted relative to Polich's (2007) neuroinhibition hypothesis, which suggests that NoGo P3a reflects a stimulus-driven cortical mechanism involving rapid neural inhibition to enhance focal attention. This perspective relates P3a to activity in frontal areas (i.e., anterior cingulate) and does not provide a full account of the distributed source outcomes identified in this study. NoGo performance monitoring may explain the present findings more completely, as monitoring requires attention, memory, stimulus- and response-processing, which engage a wide network of cortical areas largely overlapping the LA-P3a sources (i.e., anterior cingulate, medial frontal cortex, prefrontal cortex: BAs 6, 8, 9, 10, 11, 24, 25, 32; Ullsperger et

al., 2014). An explicit mechanism for NoGo P3a was not provided with this account, although attention and memory processing related to P3a is considered to support this view (Huster et al., 2013). Hence, we tentatively propose an explanation that connects both the neuroinhibition and performance monitoring accounts to explain the outcomes associated with the simple equiprobable NoGo P3a. That is, in relation to equiprobable Go/NoGo task demands, and the present findings, rapid neuronal inhibition could drive an internally directed shift in attention in correct NoGo trials. In other words, NoGo P3a could reflect a re-orienting of attention towards the self, perhaps to ensure (or confirm) that static motor behaviour was maintained correctly. This extrapolated neuroinhibition account implies that NoGo P3a reflects an attentional mechanism that serves performance monitoring in this context. But this may not apply in all tasks; variations of the P3a mechanism could be evident in other tasks separate from performance monitoring (e.g., passive mismatch tasks).

Regarding the functional implications above, an internally directed shift in attention would not be essential for successful NoGo performance, although it could facilitate task processing (i.e., monitoring, evaluation, and subsequent adjustments). Also, attention towards the passive maintenance of static behaviour *per se*, would be unlikely in incorrect NoGo trials, given that those trials involve alternate processes resulting in explicit commission errors. Moreover, shifting attention may be considered a relatively indifferent or effortless process for healthy young adults (Barry & Rushby, 2006; Recio et al., 2009; Schacht et al., 2009).

Research linking P3 (P3a) to dopaminergic/serotonergic activity (e.g., Albrecht et al., 2010; Antolin et al., 2009; Berman et al., 2006; Griskova-Bulanova et al., 2016; Hill et al., 1998; Frodl-Bauch et al., 1999; Hansenne et al., 1995; Iijima et al., 2009; Krämer et al., 2007; Mulert et al., 2006; Ohbayashi et al., 2017; Polich & Criado, 2006; Takeshita & Ogura, 1994; Vogel et al., 2006) and delta/theta oscillations (e.g., Barry et al., 2010, 2012, 2014c, 2018b, 2020a; Başar-Eroglu et al., 1992; De Blasio & Barry, 2013b, 2018; Demiralp et al., 2001; Kolev et al., 1997; Spencer & Polich, 1999; Yordanova & Kolev, 1998), could also reinforce the idea that NoGo P3a reflects an attentional component of performance monitoring, consistent with the neuroinhibition hypothesis (Polich, 2007). Frontal and subcortical dopaminergic systems are thought to play a role in both attention (Anderson et al., 2016; Dang et al., 2012; Matthysse, 1978; Nieoullon, 2002; Noudoost & Moore, 2011) and performance monitoring (which might also involve serotonergic activity: Ullsperger et al., 2014). Furthermore, EEG delta oscillations have been associated with motivated attention related to the evaluation of *internal* or external stimuli (see Knyazev, 2012). Theta-band activity is also related to attention and cognitive control; specifically, frontal-midline theta, which is thought to originate mostly in the mid-cingulate area, has been related to integrated processing across distributed cortical sources involved in action selection (see Cavanagh & Frank, 2014; Huster et al., 2013; Jensen & Colgin, 2007; Mizuseki et al., 2009), as well as neuronal inhibition to facilitate adaptive control (Cavanagh & Frank, 2014; Medalla & Barbas, 2009).

Together, these findings can support an integration of research linking NoGo P3a to controlled attention and the monitoring of behaviour, possibly involving motivated and internally directed shifts in attention to instantiate performance monitoring. However, it is important to note that this is a tentative hypothesis given that dopamine/serotonin and delta/theta activity are implicated in a range of psychological functions. It is also worth noting that this account may also be comparable to theories linking the Go (or target) P3 to response monitoring, or the re-activation of stimulus-response patterns (Verleger et al., 2005, 2016), indicating some potential for further integration with these perspectives.

4.5. Further considerations and limitations

An unsurprising finding in this study was that ERP blurring effects can have an impact on ERP component source outcomes. It is also interesting that the LA-P3a sources were a closer match to previous SL-P3a source outcomes, relative to the SL-P3a sources in this study. A possible explanation for this is that ERP blurring effects may be more pronounced in larger samples, as more variance is collapsed during ERP averaging. If that is the case, then the development and implementation of ERP latency-adjustment procedures and trial-level ERP measures will be critical for future ERP research within larger samples.

The simple data-driven latency-adjustment procedure designed for this investigation successfully controlled P3a latency jitter within and between subjects, enabling a clean isolation and quantification of the NoGo P3a across trials. Similar to other procedures used to control P3 latency jitter (e.g., Lange et al., 1997; Thornton, 2008; Woody, 1967), this technique may be useful to isolate other prominent ERP components (e.g., N1b); although it is unlikely that it could reliably isolate small ERP components (e.g., P1 or N1a). Alternate techniques may be needed to account for ERP latency jitter in smaller components; possible solutions could be shifted factor analysis (see Harshman et al., 2003; Knuth, 2006; Kohl et al., 2010; Mørup et al., 2007) or Residue Iterative Decomposition (RIDE; e.g., Ouyang et al., 2011). Indeed, a limitation of this study was that it does not control the potential latency variability in other ERP components overlapping the NoGo P3a. Here, the latency-adjusted PCA was restricted to LA-P3 to minimise the potential influence of other latency-variable components; however, shifted factor analysis or RIDE may provide a more optimal solution. Other PCA rotation criteria may also provide a more 'realistic' P3a measure than Varimax (Dien, 1998, 2006; Dien et al., 2005; Scharf & Nestler, 2018a, 2018b, 2019); however, Varimax still provides meaningful solutions and was favoured here for its simplicity and comparability with previous PCA studies of the ERPs in this task (e.g., Barry et al., 2014a, 2014b, 2016a, 2018a, 2019a, 2020b; Barry & De Blasio, 2013; Fogarty et al., 2018, 2019; Karamacoska et al., 2017, 2018a, 2018b, 2019).

Restricting the PCA to the P3 time-window could also be considered to limit our signal separation by not including more complete ERP data to enable other factors to be separated out. In this case, extraneous data should be low in the LA-P3a PCA input as the ERP data was clipped

tightly around the P3 wave identified across and within subjects. Nevertheless, we had also quantified LA-P3a (averaged within subjects) using a much broader epoch to match the timepoints in the stimulus-locked PCA input (i.e., ± 425 ms around LA-P3a) and this did not change the nature of the correlations; although certain LA-P3a sources did fall below threshold (i.e., precuneus and postcentral gyrus), perhaps due to the different signal-to-noise ratio associated with averaging. The restricted single-trial solution was used as the optimal approach to present a more simplified and valid analysis of LA-P3a (including trial variance) with minimal influence from extraneous latency variable components.

The fact that no rare NoGo conditions were tested in this study is a limitation, as it would be useful to compare the NoGo P3 in this paradigm with the NoGo P3 in tasks requiring effortful motor control. Analysing LA-P3a across tasks could clarify whether task-specific NoGo P3 components reflect equivalent processes interacting with different task demands, as has been suggested (Polich, 2007). The omission of a more demanding NoGo condition does not change the major findings in this study, which show that NoGo P3a in the auditory equiprobable task is not a practical measure of response inhibition in healthy young adults. Importantly, this finding is specific to healthy young adults, and may not apply to children, who find this paradigm more difficult due to immature executive control processing (e.g., Barry et al., 2014a; Johnstone et al., 2005; Jonkman, 2003, 2006). It is also unclear if these findings generalise to older adults, or adults with cognitive or behavioural difficulties, given that P3 and control processing may differ in these groups relative to healthy adults (e.g., Kamarajan et al., 2005a, 2005b; Vallesi, 2011; Wu et al., 2014; B. Yang et al., 2009; L. Yang et al., 2015).

The LRP outcomes in this study (and those previous) should be viewed with some caution, given that they are based on ERP difference waveforms, which can be influenced by the amplitudes of other lateralised components occurring in the pre-response period (e.g., N2b). In this study, the difference waveforms were low-pass filtered to help isolate LRP; however, further investigation is needed to clarify its relationship with overlapping components. Future research should also clarify the role of positive LRP amplitudes, and determine if there are more optimal ERP measures of response preparation in tasks with only one motor response.

4.6. Conclusion

This investigation controlled NoGo P3a latency jitter within and between participants to investigate the functionality of that component in the auditory equiprobable task, in a large sample of healthy young adults. The latency-adjustment (or *correction*) used in this study enabled the clear extraction of NoGo P3a using temporal PCA, permitting a novel analysis of the component's behavioural and neuronal correlates, in a manner that accounts for trial variance with unusually-high statistical power. Comparing the LA-P3a outcomes to the typical SL-P3a in this study demonstrated the significant ERP blurring effect associated with averaging latency-variable ERP components, with novel (but unsurprising) insight into the detrimental impact that blurring effects

can have on cortical source solutions. These outcomes provide valuable information regarding the functional significance of the NoGo P3a, without the blurring effect, and encourage the control of ERP latency jitter in future research.

In this study, the link between the equiprobable NoGo P3a and inhibitory demands was inconsequential, and on average, healthy young adults did not require response inhibition in the auditory equiprobable task; consistent with research in the visual modality (Wessel, 2018a). Accordingly, the NoGo P3a in this simple task cannot be used to index response inhibition in healthy young adults, and alternate task designs are recommended for the study of response inhibition. Despite that, the equiprobable task is still valuable for investigating a range of other information and control processes (e.g., attention and response selection), and is the most efficient Go/NoGo variant for collecting data in each condition. However, continuing research is needed to clarify the components and processing in this task, particularly given its popular use in psychophysiology.

References

Aarts, E., & Roelofs, A. (2011). Attentional control in anterior cingulate cortex based on probabilistic cueing. *Journal of Cognitive Neuroscience*, *23*(3), 716–727. https://doi.org/10.1162/jocn.2010.21435

Adelhöfer, N., & Beste, C. (2020). Pre-trial theta band activity in the ventromedial prefrontal cortex correlates with inhibition-related theta band activity in the right inferior frontal cortex. *NeuroImage, 219*, Article 117052. https://doi.org/10.1016/j.neuroimage.2020.117052

Albert, J., López-Martín, S., Hinojosa, J. A., & Carretié, L. (2013). Spatiotemporal characterisation of response inhibition. *NeuroImage*, *76*(1), 272–281. https://doi.org/10.1016/j.neuroimage.2013.03.011

Albrecht, D. S., Karaken, D. A., Christian, B. T., Dzemidzic, M., & Yoder, K. K. (2014). Cortical dopamine release during a behavioural response inhibition task. *Synapse*, *68*(6), 266–274. https://doi.org/10.1002/syn.21736

Albrecht, M. A., Martin-Iverson, M. T., Price, G., Lee, J., & Iyyalol, R. (2011). Dexamphetamine-induced reduction of P3a and P3b in healthy participants. *Journal of Psychopharmacology*, *25*(12), 1623–1631. https://doi.org/10.1177/0269881110376686

Anderer, P., & Saletu, B. (2013). Fundamentals of low-resolution brain electromagnetic tomography. In E. Nofzinger, P. Maquet, & M. J. Thorpy (Eds.), *Neuroimaging of sleep and sleep disorders* (pp. 72–81). Cambridge University Press.

Anderson, B. A., Kuwabara, H., Wong, D. F., Gean, E. G., Rahmim, A., Brašić, J. R., George, N., Frolov, B., Courtney, S. M., & Yantis, S. (2016). The role of dopamine in value-based attentional orienting. *Current Biology*, *26*(4), 550–555. https://doi.org/10.1016/j.cub.2015.12.062

Andreu, C. I., Palacios, I., Moënne-Loccoz, C., López, V., Franken, I. H., Cosmelli, D., & Slagter, H. A. (2019). Enhanced response inhibition and reduced midfrontal theta activity in experienced Vipassana meditators. *Scientific Reports*, *9*(1), 1–11. https://doi.org/10.1038/s41598-019-49714-9

Antolin, T., Berman, S. M., Conner, B. T., Ozkaragoz, T. Z., Sheen, C. L., Ritchie, T. L., & Noble, E. P. (2009). D2 dopamine receptor (DRD2) gene, P300, and personality in children of alcoholics. *Psychiatry Research*, *166*(2–3), 91–101. https://doi.org/10.1016/j.psychres.2007.12.005

Arbula, S., Pacella, V., De Pellegrin, S., Rossetto, M., Denaro, L., D'Avella, D., Puppa, A. D., & Vallesi, A. (2017). Addressing the selective role of distinct prefrontal areas in response suppression: a study with brain tumor patients. *Neuropsychologia*, *100*, 120–130. https://doi.org/10.1016/j.neuropsychologia.2017.04.018

Aron, A. R., & Poldrack, R. A. (2006). Cortical and subcortical contributions to stop signal

response inhibition: Role of the subthalamic nucleus. *Journal of Neuroscience, 26*(9), 2424–2433. https://doi.org/10.1523/JNEUROSCI.4682-05.2006

Bachiller, A., Romero, S., Molina, V., Alonso, J. F., Mañanas, M. A., Poza, J., & Hornero, R. (2018). Auditory P3a and P3b neural generators in schizophrenia: An adaptive sLORETA P300 localization approach. *Schizophrenia Research, 169*(1–3), 318–325. https://doi.org/10.1016/j.schres.2015.09.028

Banquet, J. P., Renault, B., & Lesèvre, N. (1981). Effect of task and stimulus probability on evoked potentials. *Biological Psychology, 13*, 203–214. https://doi.org/10.1016/0301-0511(81)90036-3

Barry, R. J., & De Blasio, F. M. (2012). EEG-ERP phase dynamics of children in the auditory Go/NoGo task. *International Journal of Psychophysiology*, *86*(3), 251–261. https://doi.org/10.1016/j.ijpsycho.2012.10.001

Barry, R. J., & De Blasio, F. M. (2013). Sequential processing in the equiprobable auditory Go/NoGo task: A temporal PCA study. *International Journal of Psychophysiology*, *89*(1), 123–127. https://doi.org/10.1016/j.ijpsycho.2013.06.012

Barry, R. J., & De Blasio, F. M. (2015). Performance and ERP components in the equiprobable go/no-go task: Inhibition in children. *Psychophysiology, 52*(9), 1228–1237. https://doi.org/10.1111/psyp.12447

Barry, R. J., De Blasio, F. M., & Borchard, J. P. (2014a). Sequential processing in the equiprobable auditory Go/NoGo task: Children vs. adults. *Clinical Neurophysiology, 125*(10), 1995–2006. http://doi.org/10.1016/j.clinph.2014.02.018

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2014b). Caffeine effects on erp components and performance in an equiprobable auditory go/nogo task. *Journal of Caffeine Research*, *4*(3), 83–92. https://doi.org/10.1089/jcr.2014.0011

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2016a). Sequential processing in young and older adults in the equiprobable auditory Go/NoGo task. *Clinical Neurophysiology*, *127*(5), 2273–2285. https://doi.org/10.1016/j.clinph.2016.02.010

Barry, R. J., De Blasio, F. M., De Pascalis, V., & Karamacoska, D. (2014c). Preferred EEG brain states at stimulus onset in a fixed interstimulus interval equiprobable auditory Go/NoGo task: a definitive study. *International Journal of Psychophysiology*, *94*(1), 42–58. https://doi.org/10.1016/j.ijpsycho.2014.07.005

Barry, R. J., De Blasio, F. M., & Fogarty, J. S. (2018a). A processing schema for children in the auditory equiprobable Go/NoGo task: ERP components and behaviour. *International Journal of Psychophysiology*, *123*, 74–79. https://doi.org/10.1016/j.ijpsycho.2017.10.014

Barry, R. J., De Blasio, F. M., & Fogarty, J. S. (2019a). Caffeine affects children's ERPs and performance in an equiprobable go/no-go task: Testing a processing schema.

Psychophysiology, *56*(5), Article e13330. https://doi.org/10.1111/psyp.13330

Barry, R. J., De Blasio, F. M., Fogarty, J. S., & Clarke, A. R. (2020a). Preferred EEG brain states at stimulus onset in normal ageing: Explorations in a fixed interstimulus interval Go/NoGo task. *International Journal of Psychophysiology*, *152*, 87–101. https://doi.org/10.1016/j.ijpsycho.2020.03.001

Barry, R. J., De Blasio, F. M., Fogarty, J. S., & Karamacoska, D. (2016b). ERP Go/NoGo condition effects are better detected with separate PCAs. *International Journal of Psychophysiology*, *106*, 50–64. https://doi.org/10.1016/j.ijpsycho.2016.06.003

Barry, R. J., De Blasio, F., Rushby, J. A., & Clarke, A. R. (2010). Brain dynamics in the auditory Go/NoGo task as a function of EEG frequency. *International Journal of Psychophysiology*, *78*(2), 115–128. https://doi.org/10.1016/j.ijpsycho.2010.06.357

Barry, R. J., Fogarty, J. S., & De Blasio, F. M. (2020b). Caffeine as a tool to explore active cognitive processing stages in two-choice tasks. *Journal of Caffeine and Adenosine Research*, *10*(2), 71–83. https://doi.org/10.1089/caff.2019.0021

Barry, R. J., Fogarty, J. S., De Blasio, F. M., & Karamacoska, D. (2018b). EEG phase states at stimulus onset in a variable-ISI Go/NoGo task: Effects on ERP components. *Biological Psychology*, *134*, 89–102. https://doi.org/10.1016/j.biopsycho.2018.02.005

Barry, R. J., Johnstone, S. J., Clarke, A. R., Rushby, J. A., Brown, C. R., & McKenzie, D. N. (2007). Caffeine effects on ERPs and performance in an auditory Go/NoGo task. *Clinical Neurophysiology*, *118*(12), 2692–2699. https://doi.org/10.1016/j.clinph.2007.08.023

Barry, R. J., & Rushby, J. A. (2006). An orienting reflex perspective on anteriorisation of the P3 of the event-related potential. *Experimental Brain Research*, *173*(3), 539–545. https://doi.org/10.1007/s00221-006-0590-8

Barry, R. J., Steiner, G. Z., De Blasio, F. M., Fogarty, J. S., Karamacoska, D., & MacDonald, B. (2020c). Components in the P300: Don't forget the Novelty P3!. *Psychophysiology*, Article e13371. https://doi.org/10.1111/psyp.13371

Başar, E. (1998). *Brain Function and Oscillations. I. Brain Oscillations: Principles and Approaches*. Springer, Berlin, Heidelberg.

Başar, E. (1999). *Brain Function and Oscillations. II. Integrative Brain Function. Neurophysiology and Cognitive Processes*. Springer, Berlin, Heidelberg.

Başar, E., Başar-Eroglu, C., Karakaş, S., & Schürmann, M. (2001). Gamma, alpha, delta, and theta oscillations govern cognitive processes. *International Journal of Psychophysiology*, *39*(2–3), 241–248. https://doi.org/10.1016/s0167-8760(00)00145-8

Başar-Eroglu, C., Başar, E., Demiralp, T., & Schürmann, M. (1992). P300-response: possible psychophysiological correlates in delta and theta frequency channels. A review. *International Journal of Psychophysiology*, *13*(2), 161–179.

https://doi.org/10.1016/0167-8760(92)90055-G

Başar-Eroglu, C., & Demiralp, T. (2001). Event-related theta oscillations: an integrative and comparative approach in the human and animal brain. *International Journal of Psychophysiology*, *39*(2–3), 167–195. https://doi.org/10.1016/S0167-8760(00)00140-9

Berman, S. M., Noble, E. P., Antolin, T., Sheen, C., Conner, B. T., & Ritchie, T. (2006). P300 development during adolescence: effects of DRD2 genotype. *Clinical Neurophysiology*, *117*(3), 649–659. https://doi.org/10.1016/j.clinph.2005.11.012

Beste, C., Stock, A. K., Epplen, J. T., & Arning, L. (2016). Dissociable electrophysiological subprocesses during response inhibition are differentially modulated by dopamine D1 and D2 receptors. *European Neuropsychopharmacology*, *26*(6), 1029–1036. https://doi.org/10.1016/j.euroneuro.2016.03.002

Beste, C., Willemssen, R., Saft, C., & Falkenstein, M. (2010). Response inhibition subprocesses and dopaminergic pathways: basal ganglia disease effects. *Neuropsychologia*, *48*(2), 366–373. https://doi.org/10.1016/j.neuropsychologia.2009.09.023

Bethea, C. L., Lu, N. Z., Gundlah, C., & Streicher, J. M. (2002). Diverse actions of ovarian steroids in the serotonin neural system. *Frontiers in Neuroendocrinology*, *23*(1), 41–100. https://doi.org/10.1006/frne.2001.0225

Blumenfeld, R. S., & Ranganath, C. (2007). Prefrontal cortex and long-term memory encoding: an integrative review of findings from neuropsychology and neuroimaging. *Neuroscience*, *13*(3), 280–291. https://doi.org/10.1177/1073858407299290

Bokura, H., Yamaguchi, S., & Kobayashi, S. (2001). Electrophysiological correlates for response inhibition in a Go/NoGo task. *Clinical Neurophysiology*, *112*(12), 2224–2232. https://doi.org/10.1016/s1388-2457(01)00691-5

Borchard, J. P., Barry, R. J., & De Blasio, F. M. (2015). Sequential processing in an auditory equiprobable Go/NoGo task with variable interstimulus interval. *International Journal of Psychophysiology*, *97*(2), 145–152. https://doi.org/10.1016/j.ijpsycho.2015.05.010

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652. http://doi.org/10.1037/0033-295X.108.3.624

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, *8*(12), 539–546. http://doi.org/10.1016/j.tics.2004.10.003

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature*, *402*(6758), 179–181. https://doi.org/10.1038/46035

Boulinguez, P., Ballanger, B., Granjon, L., & Benraiss, A. (2009). The paradoxical effect of warning on reaction time: demonstrating proactive response inhibition with event-

related potentials. *Clinical Neurophysiology*, *120*(4), 730–737. https://doi.org/10.1016/j.clinph.2009.02.167

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106–113. https://doi.org/10.1016/j.tics.2011.12.010

Braver, T. S., Barch, D. M., Gray, J. R., Molfese, D. L., & Snyder, A. (2001). Anterior cingulate cortex and response conflict: Effects of frequency, inhibition and errors. *Cerebral Cortex*, *11*(9), 825–836. https://doi.org/10.1093/cercor/11.9.825

Brittain, J. S., & Brown, P. (2014). Oscillations and the basal ganglia: motor control and beyond. *NeuroImage*, *85*, 637–647. https://doi.org/10.1016/j.neuroimage.2013.05.084

Bruin, K. J., & Wijers, A. A. (2002). Inhibition, response mode, and stimulus probability: A comparative event-related potential study. *Clinical Neurophysiology*, *113*(7), 1172–1182. http://doi.org/10.1016/S1388-2457(02)00141-4

Bruin, K. J., Wijers, A. A., & Van Staveren, A. S. J. (2001). Response priming in a go/nogo task: do we have to explain the go/nogo N2 effect in terms of response activation instead of inhibition?. *Clinical Neurophysiology*, *112*(9), 1660–1671. https://doi.org/10.1016/s1388-2457(01)00601-0

Carter, C. S., MacDonald, A. W., 3rd, Ross, L. L., & Stenger, V. A. (2001). Anterior cingulate cortex activity and impaired self-monitoring of performance in patients with schizophrenia: an event-related fMRI study. *The American Journal of Psychiatry*, *158*(9), 1423–1428. https://doi.org/10.1176/appi.ajp.158.9.1423

Catalan, M. J., Honda, M., Weeks, R. A., Cohen, L. G., & Hallet, M. (1998). The functional neuroanatomy of simple and complex sequential finger movements: A PET study. *Brain*, *121*(2), 253–264. https://doi.org/10.1093/brain/121.2.253

Cavanagh, J. F., & Frank, M. J. (2014). Frontal theta as a mechanism for cognitive control. *Trends in Cognitive Sciences*, *18*(8), 414–421. https://doi.org/10.1016/j.tics.2014.04.012

Cavanna, A. E., & Trimble, M. R. (2006). The precuneus: a review of its functional anatomy and behavioural correlates. *Brain 129*(3), 564–583. https://doi.org/10.1093/brain/awl004

Chmielewski, W. X., & Beste, C. (2019). Stimulus Feature Conflicts Enhance Motor Inhibitory Control Processes in the Lateral Prefrontal Cortex. *Journal of Cognitive Neuroscience*, *31*(9), 1430–1442. https://doi.org/10.1162/jocn_a_01424

Clark, L., Roiser, J. P., Cools, R., Rubinsztein, D. C., Sahakian, B. J., & Robbins, T. W. (2005). Stop signal response inhibition is not modulated by tryptophan depletion or the serotonin transporter polymorphism in healthy volunteers: implications for the 5-HT theory of impulsivity. *Psychopharmacology*, *182*(4), 570–578. https://doi.org/10.1007/s00213-005-0104-6

Coles, M. G. (1989). Modern mind-brain reading: Psychophysiology, physiology, and cognition. *Psychophysiology*, *26*(3), 252–269. https://doi.org/10.1111/j.1469-8986.1989.tb01916.x

Criaud, M., & Boulinguez, P. (2013). Have we been asking the right questions when assessing response inhibition in go/no-go tasks with fMRI? A meta-analysis and critical review. *Neuroscience and Biobehavioral Reviews*, *37*(1), 11–23. https://doi.org/10.1016/j.neubiorev.2012.11.003

Croft, R. J., & Barry, R. J. (2000). EOG correction of blinks with saccade coefficients: A test and revision of the aligned-artefact average solution. *Clinical Neurophysiology*, *111*(3), 444–451. https://doi.org/10.1016/S1388-2457(99)00296-5

Daly, E., Ecker, C., Hallahan, B., Deeley, Q., Craig, M., Murphy, C., Johnston, P., Spain, D., Gillan, N., Gudbrandsen, M., Brammer, M., Giampietro, V., Lamar, M., Page, L., Toal, F., Schmitz, N., Cleare, A., Robertson, D., Rubia, K., & Murphy, D. G. (2014). Response inhibition and serotonin in autism: a functional MRI study using acute tryptophan depletion. *Brain*, *137*(Pt 9), 2600–2610. https://doi.org/10.1093/brain/awu178

Dang, L. C., O'Neil, J. P., & Jagust, W. J. (2012). Dopamine supports coupling of attention-related networks. *Journal of Neuroscience*, *32*(28), 9582–9587. https://doi.org/10.1523/JNEUROSCI.0909-12.2012

Daw, N. D., Kakade, S., & Dayan, P. (2002). Opponent interactions between serotonin and dopamine. *Neural Networks*, *15*(4–6), 603–616. https://doi.org/10.1016/s0893-6080(02)00052-7

Debener, S., Ullsperger, M., Siegel, M., Fiehler, K., Von Cramon, D. Y., & Engel, A. K. (2005). Trial-by-trial coupling of concurrent electroencephalogram and functional magnetic resonance imaging identifies the dynamics of performance monitoring. *Journal of Neuroscience*, *25*(50), 11730–11737. https://doi.org/10.1523/JNEUROSCI.3286-05.2005

De Blasio, F. M., & Barry, R. J. (2013a). Prestimulus alpha and beta determinants of ERP responses in the Go/NoGo task. *International Journal of Psychophysiology*, *89*(1), 9–17. https://doi.org/10.1016/j.ijpsycho.2013.04.018

De Blasio, F. M., & Barry, R. J. (2013b). Prestimulus delta and theta determinants of ERP responses in the Go/NoGo task. *International Journal of Psychophysiology*, *87*(3), 279–288. https://doi.org/10.1016/j.ijpsycho.2012.09.016

De Blasio, F. M., & Barry, R. J. (2018). Prestimulus delta and theta contributions to equiprobable Go/NoGo processing in healthy ageing. *International Journal of Psychophysiology*, *130*, 40–52. https://doi.org/10.1016/j.ijpsycho.2018.05.005

De Blasio, F. M., & Barry, R. J. (2020). Prestimulus alpha and beta contributions to

equiprobable Go/NoGo processing in healthy ageing. *International Journal of Psychophysiology*, *155*, 32–40. https://doi.org/10.1016/j.ijpsycho.2020.05.009

Demiralp, T., Ademoglu, A., Comerchero, M., & Polich, J. (2001). Wavelet analysis of P3a and P3b. *Brain Topography*, *13*(4), 251–267. https://doi.org/10.1023/A:1011102628306

Dien, J. (1998). Addressing misallocation of variance in principal components analysis of event-related potentials. *Brain Topography*, *11*(1), 43–55. https://doi.org/10.1023/A

Dien, J. (2006). Progressing towards a consensus on PCA of ERPs. *Clinical Neurophysiology*, *117*(3), 699–702. https://doi.org/10.1016/j.clinph.2005.09.029

Dien, J., Beal, D. J., & Berg, P. (2005). Optimizing principal components analysis of event-related potentials: matrix type, factor loading weighting, extraction, and rotations. *Clinical Neurophysiology*, *116*(8), 1808–1825. https://doi.org/10.1016/j.clinph.2004.11.025

Dien, J., & Frishkoff, G. A. (2005). Introduction to principal components analysis of event-related potentials. In T. Handy (Ed.), *Event-related potentials: A methods handbook* (pp. 189–208). Cambridge, MA: MIT Press.

Dien, J., Spencer, K. M., & Donchin, E. (2004). Parsing the late positive complex: mental chronometry and the ERP components that inhabit the neighborhood of the P300. *Psychophysiology*, *41*(5), 665–678. https://doi.org/10.1111/j.1469-8986.2004.00193.x

DiGuiseppi, J., & Tadi, P. (2019). Neuroanatomy, postcentral gyrus. StatPearls. Treasure Island. https://www.ncbi.nlm.nih.gov/books/NBK549825/

Dimoska, A., Johnstone, S. J., & Barry, R. J. (2006). The auditory-evoked N2 and P3 components in the stop-signal task: indices of inhibition, response-conflict or error-detection? *Brain and Cognition*, *62*(2), 98–112. https://doi.org/10.1016/j.bandc.2006.03.011

Dippel, G., Chmielewski, W., Mückschel, M., & Beste, C. (2016). Response mode-dependent differences in neurofunctional networks during response inhibition: an EEG-beamforming study. *Brain Structure & Function*, *221*(8), 4091–4101. https://doi.org/10.1007/s00429-015-1148-y

Di Russo, F., Zaccara, G., Ragazzoni, A., & Pallanti, S. (2000). Abnormal visual event-related potentials in obsessive-compulsive disorder without panic disorder or depression comorbidity. *Journal of Psychiatric Research*, *34*(1), 75–82. https://doi.org/10.1016/S0022-3956(99)00030-8

Dluzen, D. E., & Ramirez, V. D. (1984). Bimodal effect of progesterone on in vitro dopamine function of the rat corpus striatum. *Neuroendocrinology*, *39*(2), 149–155. https://doi.org/10.1159/000123971

Donkers, F. C. L., & Van Boxtel, G. J. M. (2004). The N2 in go/no-go tasks reflects conflict monitoring not response inhibition. *Brain and Cognition*, *56*(2), 165–176.

http://doi.org/10.1016/j.bandc.2004.04.005

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica, 101*(2–3), 267–291. http://doi.org/10.1016/S0001-6918(99)00008-6

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (2002). Inhibition-related ERP components: Variation with modality, age, and time-on-task. *Journal of Psychophysiology*, *16*(3), 167–175. https://doi.org/10.1027//0269-8803.16.3.167

Fallgatter, A. J., & Strik, W. K. (1999). The NoGo-anteriorization as a neurophysiological standard-index for cognitive response control. *International Journal of Psychophysiology*, *32*(3), 233–238. https://doi.org/10.1016/s0167-8760(99)00018-5

Fogarty, J. S., Barry, R. J., De Blasio, F. M., & Steiner, G. Z. (2018). ERP components and behavior in the auditory equiprobable go/no-go task: Inhibition in young adults. *Psychophysiology*, *55*(7), Article e13065. https://doi.org/10.1111/psyp.13065

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2019). Sequential processing in the classic oddball task: ERP components, probability, and behavior. *Psychophysiology*, *56*(3), Article e13300. https://doi.org/10.1111/psyp.13300

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2020). The first 250 ms of auditory processing: No evidence of early processing negativity in the Go/NoGo task. *Scientific Reports*, *10*(1), Article 4041. https://doi.org/10.1038/s41598-020-61060-9

Ford, J. M., Pfefferbaum, A., Tinklenberg, J. R., & Kopell, B. S. (1982). Effects of perceptual and cognitive difficulty on P3 and RT in young and old adults. *Electroencephalography and Clinical Neurophysiology*, *54*(3), 311–321. https://doi.org/10.1016/0013-4694(82)90180-8

Frodl-Bauch, T., Bottlender, R., & Hegerl, U. (1999). Neurochemical substrates and neuroanatomical generators of the event-related P300. *Neuropsychobiology*, *40*(2), 86–94. https://doi.org/10.1159/000026603

Ghahremani, D. G., Lee, B., Robertson, C. L., Tabibnia, G., Morgan, A. T., De Shetler, N., Brown, A. K., Monterosso, J. R., Aron, A. R., Mandelkern, M. A., & Poldrack, R. A. (2012). Striatal dopamine D2/D3 receptors mediate response inhibition and related activity in frontostriatal neural circuitry in humans. *Journal of Neuroscience*, *32*(21), 7316–7324.

Gonzalez-Rosa, J. J., Inuggi, A., Blasi, V., Cursi, M., Annovazzi, P., Comi, G., Falini, A., & Leocani, L. (2013). Response competition and response inhibition during different choice-discrimination tasks: Evidence from ERP measured inside MRI scanner. *International Journal of Psychophysiology, 89*(1), 37–47. https://doi.org/10.1016/j.ijpsycho.2013.04.021

Grech, R., Cassar, T., Muscat, J., Camilleri, K. P., Fabri, S. G., Zervakis, M., Xanthopoulos, P.,

Sakkalis, V., & Vanrumste, B. (2008). Review on solving the inverse problem in EEG source analysis. *Journal of Neuroengineering and Rehabilitation*, *5*(1), Article 25. https://doi.org/10.1186/1743-0003-5-25

Griskova-Bulanova, I., Griksiene, R., Voicikas, A., & Ruksenas, O. (2016). Go and NoGo: modulation of electrophysiological correlates by female sex steroid hormones. *Psychopharmacology*, *233*, 2607–2615. https://doi.org/10.1007/s00213-016-4311-0

Güntekin, B., & Başar, E. (2016). Review of evoked and event-related delta responses in the human brain. *International Journal of Psychophysiology*, *103*, 43–52. https://doi.org/10.1016/j.ijpsycho.2015.02.001

Halder, T., Talwar, S., Jaiswal, A. K., & Banerjee, A. (2019). Quantitative evaluation in estimating sources underlying brain oscillations using current source density methods and beamformer approaches. *Eneuro*, *6*(4), 1–14. https://doi.org/10.1523/ENEURO.0170-19.2019

Hansenne, M., Pitchot, W., Gonzalez Moreno, A., Papart, P., Timsit-Berthier, M., & Ansseau, M. (1995). Catecholaminergic function and P300 amplitude in major depressive disorder (P300 and catecholamines). *Electroencephalography and Clinical Neurophysiology*, *96*(2), 194–196. https://doi.org/10.1016/0168-5597(94)00317-8

Harmony, T. (2013). The functional significance of delta oscillations in cognitive processing. *Frontiers in Integrative Neuroscience*, *7*, Article 83. https://doi.org/10.3389/fnint.2013.00083

Harper, J., Malone, S. M., Bachman, M. D., & Bernat, E. M. (2016). Stimulus sequence context differentially modulates inhibition-related theta and delta band activity in a go/no-go task. *Psychophysiology*, *53*(5), 712–722. https://doi.org/10.1111/psyp.12604

Harper, J., Malone, S. M., & Bernat, E. M. (2014). Theta and delta band activity explain N2 and P3 ERP components in a go/no-go task. *Clinical Neurophysiology*, *125*, 124–132. https://doi.org/10.1016/j.clinph.2013.06.025

Harshman, R. A., Hong, S., & Lundy, M. E. (2003). Shifted factor analysis - Part I: Models and properties. *Journal of Chemometrics*, *17*(7), 363–378. https://doi.org/10.1002/cem.808

He, B., & Ding, L. (2013) Electrophysiological Mapping and Neuroimaging. In B. He (Ed.) *Neural Engineering* (pp. 499–543). Boston, MA: Springer. https://doi.org/10.1007/978-1-4614-5227-0_12

Hill, S. Y., Locke, J., Zezza, N., Kaplan, B., Neiswanger, K., Steinhauer, S. R., Wipprecht, G., & Xu, J. (1998). Genetic association between reduced P300 amplitude and the DRD2 dopamine receptor A1 allele in children at high risk for alcoholism. *Biological Psychiatry*, *43*(1), 40–51. https://doi.org/10.1016/s0006-3223(97)00203-5

Hoshi, E. (2006). Functional specialization within the dorsolateral prefrontal cortex: A review of anatomical and physiological studies of non-human primates. *Neuroscience*

Research, 54(2), 73–84. https://doi.org/10.1016/j.neures.2005.10.013

Hull, J., & Harsh, J. (2001). P300 and sleep-related positive waveforms (P220, P450, and P900) have different determinants. *European Sleep Research Society*, *10*, 9–17. https://doi.org/10.1046/j.1365-2869.2001.00238.x

Humby, T., Eddy, J. B., Good, M. A., Reichelt, A. C., & Wilkinson, L. S. (2013). A novel translational assay of response inhibition and impulsivity: effects of prefrontal cortex lesions, drugs used in ADHD, and serotonin 2C receptor antagonism. *Neuropsychopharmacology*, *38*(11), 2150–2159. https://doi.org/10.1038/npp.2013.112

Huster, R. J., Enriquez-Geppert, S., Lavallee, C. F., Falkenstein, M., & Herrmann, C. S. (2013). Electroencephalography of response inhibition tasks: functional networks and cognitive contributions. *International Journal of Psychophysiology*, *87*(3), 217–233. https://doi.org/10.1016/j.ijpsycho.2012.08.001

Huster, R. J., Messel, M. S., Thunberg, C., & Raud, L. (2020). The P300 as marker of inhibitory control - Fact or fiction?. *Cortex*, *132*, 334–348. https://doi.org/10.1016/j.cortex.2020.05.021

Iijima, M., Osawa, M., Nishitani, N., & Iwata, M. (2009). Effects of incense on brain function: evaluation using electroencephalograms and event-related potentials. *Neuropsychobiology*, *59*(2), 80–86. https://doi.org/10.1159/000209859

Jatoi, M. A., Kamel, N., Malik, A. S., & Faye, I. (2014). EEG based brain source localization comparison of sLORETA and eLORETA. *Australasian Physical & Engineering Sciences in Medicine*, *37*(4), 713–721. https://doi.org/10.1007/s13246-014-0308-3

Jensen, O., & Colgin, L. L. (2007). Cross-frequency coupling between neuronal oscillations. *Trends in Cognitive Sciences*, *11*(7), 267–269. https://doi.org/10.1016/j.tics.2007.05.003

Johnstone, S. J., Pleffer, C. B., Barry, R. J., Clarke, A. R., & Smith, J. L. (2005). Development of inhibitory processing during the go/nogo task. *Journal of Psychophysiology*, *19*(1), 11–23. https://doi.org/10.1027/0269-8803.19.1.11

Jonkman, L. M. (2006). The development of preparation, conflict monitoring and inhibition from early childhood to young adulthood; a Go/Nogo ERP study. *Brain Research*, *1097*(1), 181–193. https://doi.org/10.1016/j.brainres.2006.04.064

Jonkman, L. M., Lansbergen, M., & Stauder, J. E. A. (2003). Developmental differences in behavioral and event-related brain responses associated with response preparation and inhibition in a go/nogo task. *Psychophysiology*, *40*(5), 752–761. https://doi.org/10.1111/1469-8986.00075

Kamarajan, C., Porjesz, B., Jones, K. A., Choi, K., Chorlian, D. B., Padmanabhapillai, A., Rangaswamy, M., Stimus, A. T., & Begleiter, H. (2004). The role of brain oscillations as functional correlates of cognitive systems: a study of frontal inhibitory control in alcoholism. *International Journal of Psychophysiology*, *51*(2), 155–180.

https://doi.org/10.1016/j.ijpsycho.2003.09.004

Kamarajan, C., Porjesz, B., Jones, K. A., Choi, K., Chorlian, D. B., Padmanabhapillai, A., Rangaswamy, M., Stimus, A. T., & Begleiter, H. (2005a). Alcoholism is a disinhibitory disorder: Neurophysiological evidence from a Go/No-Go task. *Biological Psychology, 69*(3), 353–373. https://doi.org/10.1016/j.biopsycho.2004.08.004

Kamarajan, C., Porjesz, B., Jones, K. A., Chorlian, D. B., Padmanabhapillai, A., Rangaswamy, M., Stimus, A. T., & Begleiter, H. (2005b). Spatial-anatomical mapping of NoGo-P3 in the offspring of alcoholics: evidence of cognitive and neural disinhibition as a risk for alcoholism. *Clinical Neurophysiology*, *116*(5), 1049–1061. https://doi.org/10.1016/j.clinph.2004.12.015

Kapur, S., & Remington, G. (1996). Serotonin-dopamine interaction and its relevance to schizophrenia. *The American Journal of Psychiatry*, *153*(4), 466–476. https://doi.org/10.1176/ajp.153.4.466

Karamacoska, D., Barry, R. J., & Steiner, G. Z. (2017). Resting state intrinsic EEG impacts on go stimulus-response processes. *Psychophysiology*, *54*(6), 894–903. https://doi.org/10.1111/psyp.12851

Karamacoska, D., Barry, R. J., Steiner, G. Z. (2018a). Electrophysiological underpinnings of response variability in the Go/NoGo task. *International Journal of Psychophysiology, 134,* 159–167. https://doi.org/10.1016/j.ijpsycho.2018.09.008

Karamacoska, D., Barry, R. J., & Steiner, G. Z. (2019). Using principal components analysis to examine resting state EEG in relation to task performance. *Psychophysiology*, *56*(5), Article e13327. https://doi.org/10.1111/psyp.13327

Karamacoska, D., Barry, R. J., Steiner, G. Z., Coleman, E. P., & Wilson, E. J. (2018b). Intrinsic EEG and task-related changes in EEG affect Go/NoGo task performance. *International Journal of Psychophysiology*, *125,* 17–28. https://doi.org/10.1016/j.ijpsycho.2018.01.015

Karlin, L., Martz, M. J., & Mordkoff, A. M. (1970). Motor performance and sensory-evoked potentials. *Electroencephalography and Clinical Neurophysiology*, *28*(3), 307–313. https://doi.org/10.1016/0013-4694(70)90167-7

Kayser, J., & Tenke, C. E. (2003). Optimizing PCA methodology for ERP component identification and measurement: Theoretical rationale and empirical evaluation. *Clinical Neurophysiology*, *114*(12), 2307–2325. https://doi.org/10.1016/S1388-2457(03)00241-4

Kelland, M. D., & Chiodo, L. A. (1996). Serotonergic modulation of midbrain dopamine systems. In C. R. Ashby (Ed.) *The Modulation of Dopaminergic Neurotransmission by other Neurotransmitters* (pp. 87–122). New York: CRC Press.

Keskin-Ergen, Y., Tükel, R., Aslantaş-Ertekin, B., Ertekin, E., Oflaz, S., & Devrim-Üçok, M. (2014). N2 and P3 potentials in early-onset and late-onset patients with obsessive-

compulsive disorder. *Depression and Anxiety*, *31*(12), 997–1006. https://doi.org/10.1002/da.22212

Kiehl, K. A., Smith, A. M., Hare, R. D., & Liddle, P. F. (2000). An event-related potential investigation of response inhibition in schizophrenia and psychopathy. *Biological Psychiatry*, *48*(3), 210–221. https://doi.org/10.1016/s0006-3223(00)00834-9

Kirmizi-Alsan, E., Bayraktaroglu, Z., Gurvit, H., Keskin, Y. H., Emre, M., & Demiralp, T. (2006). Comparative analysis of event-related potentials during Go/NoGo and CPT: Decomposition of electrophysiological markers of response inhibition and sustained attention. *Brain Research*, *1104*(1), 114–128. https://doi.org/10.1016/j.brainres.2006.03.010

Knight, R. T., Grabowecky, M. F., & Scabini, D. (1995). Role of human prefrontal cortex in attention control. In H. H. Jasper, S. Riggio, & P. S. Goldman-Rakic (Eds.), *Advances in neurology, Vol. 66. Epilepsy and the functional anatomy of the frontal lobe* (pp. 21–36). Raven Press.

Knuth, K. H. (2006). Differentially variable component analysis: Identifying multiple evoked components using trial-to-trial variability. *Journal of Neurophysiology*, *95*(5), 3257–3276. https://doi.org/10.1152/jn.00663.2005

Knyazev G. G. (2007). Motivation, emotion, and their inhibitory control mirrored in brain oscillations. *Neuroscience and Biobehavioral Reviews*, *31*(3), 377–395. https://doi.org/10.1016/j.neubiorev.2006.10.004

Knyazev G. G. (2012). EEG delta oscillations as a correlate of basic homeostatic and motivational processes. *Neuroscience and Biobehavioral Reviews*, *36*(1), 677–695. https://doi.org/10.1016/j.neubiorev.2011.10.002

Kohl, F., Wübbeler, G., Kolossa, D., Bar, M., Orglmeister, R., & Elster, C. (2010). Shifted factor analysis for the separation of evoked dependent MEG signals. *Physics in Medicine and Biology*, *55*(15), 4219–4230. https://doi.org/10.1088/0031-9155/55/15/002

Kok, A., Ramautar, J. R., De Ruiter, M. B., Band, G. P. H., & Ridderinkhof, K. R. (2004). ERP components associated with successful and unsuccessful stopping in a stop-signal paradigm. *Psychophysiology*, *41*(1), 9–20. https://doi.org/10.1046/j.1469-8986.2003.00127.x

Kolev, V., Demiralp, T., Yordanova, J., Ademoglu, A., & Isoglu-Alkaç, U. (1997). Time-frequency analysis reveals multiple functional components during oddball P300. *NeuroReport*, *8*(8), 2061–2065. https://doi.org/10.1097/00001756-199705260-00050

Krämer, U. M., Cunillera, T., Càmara, E., Marco-Pallarés, J., Cucurell, D., Nager, W., Bauer, P., Schüle, R., Schöls, L., Rodriguez-Fornells, A., & Münte, T. F. (2007). The impact of catechol-O-methyltransferase and dopamine D4 receptor genotypes on

neurophysiological markers of performance monitoring. *The Journal of Neuroscience, 27*(51), 14190–14198. https://doi.org/10.1523/JNEUROSCI.4229-07.2007

Landrø, N. I., Jonassen, R., Clark, L., Haug, K. B., Aker, M., Bø, R., Berg, J. P., Neumeister, A., & Stiles, T. C. (2015). Serotonin transporter polymorphisms predict response inhibition in healthy volunteers. *Neuroscience Letters, 584*, 109–112. https://doi.org/10.1016/j.neulet.2014.10.006

Lange, D. H., Pratt, H., & Inbar, G. F. (1997). Modeling and estimation of single evoked brain potential components. *IEEE transactions on BioMedical Engineering, 44*(9), 791–799. https://doi.org/10.1109/10.623048

Lara, A. H., & Wallis, J. D. (2015). The role of the prefrontal cortex in working memory: A mini review. *Frontiers in Systems Neuroscience, 9*, 1–7. https://doi.org/10.3389/fnsys.2015.00173

Laurens, K. R., Kiehl, K. A., & Liddle, P. F. (2005). A supramodal limbic-paralimbic-neocortical network supports goal-directed stimulus processing. *Human Brain Mapping, 24*(1), 35–49. https://doi.org/10.1002/hbm.20062

Liotti, M., Pliszka, S. R., Perez, R., Kothmann, D., & Woldorff, M. G. (2005). Abnormal brain activity related to performance monitoring and error detection in children with ADHD. *Cortex, 41*(3), 377–388. https://doi.org/10.1016/s0010-9452(08)70274-0

Leech, R., & Sharp, D. J. (2014). The role of the posterior cingulate cortex in cognition and disease. *Brain, 137*(1), 12–32. https://doi.org/10.1093/brain/awt162

Low, K. A. & Miller, J. (1999). The usefulness of partial information: effects of go probability in the choice/Nogo task. *Psychophysiology, 36*(3), 288–297. https://doi.org/10.1017/S0048577299980332

Luck, S. J. (2005). *An introduction to the event-related potential technique.* Cambridge, MA: MIT Press

Macoveanu, J., Hornboll, B., Elliott, R., Erritzoe, D., Paulson, O. B., Siebner, H., Knudsen, G. M., & Rowe, J. B. (2013). Serotonin 2A receptors, citalopram and tryptophan-depletion: a multimodal imaging study of their interactions during response inhibition. *Neuropsychopharmacology, 38*(6), 996–1005. https://doi.org/10.1038/npp.2012.264

Masharipov, R., Kireev, M., Korotkov, A., & Medvedev, S. (Preprint). Non-selective response inhibition in Go/NoGo task: Bayesian analysis of fMRI data. *bioRxiv,* Article 823625. https://doi.org/10.1101/823625

Matthysse, S. (1978). A theory of the relation between dopamine and attention. *Journal of Psychiatric Research, 14*(1–4), 241–248. https://doi.org/10.1016/0022-3956(78)90026-2

Medalla, M., & Barbas, H. (2009). Synapses with inhibitory neurons differentiate anterior cingulate from dorsolateral prefrontal pathways associated with cognitive control.

Neuron, *61*(4), 609–620. https://doi.org/10.1016/j.neuron.2009.01.006

Melynyte, S., Ruksenas, O., & Griskova-Bulanova, I. (2017). Sex differences in equiprobable auditory Go/NoGo task: Effects on N2 and P3. *Experimental Brain Research, 235,* 1565–1574. http://doi. org/10.1007/s00221-017-4911-x

McFarland, D. J., & Cacace, A. T. (2004). Separating stimulus-locked and unlocked components of the auditory event-related potential. *Hearing Research*, *193*(1–2), 111–120. https://doi.org/10.1016/j.heares.2004.03.014

Michel, C. M., Murray, M. M., Lantz, G., Gonzalez, S., Spinelli, L., & de Peralta, R. G. (2004). EEG source imaging. *Clinical Neurophysiology*, *115*(10), 2195–2222. https://doi.org/10.1016/j.clinph.2004.06.001

Miller, J. (1998). Effects of stimulus-response probability on choice reaction time: Evidence from the lateralized readiness potential. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(5), 1521–1534. https://doi.org/10.1037/0096-1523.24.5.1521

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*(1), 167–202. https://doi.org/10.1146/annurev.neuro.24.1.167

Miller, J. O., & Low, K. (2001). Motor processes in simple, go/no-go, and choice reaction time tasks: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(2), 266–289. https://doi.org/10.1037/0096-1523.27.2.266

Mizuseki, K., Sirota, A., Pastalkova, E., & Buzsáki, G. (2009). Theta oscillations provide temporal windows for local circuit computation in the entorhinal-hippocampal loop. *Neuron*, *64*(2), 267–280. https://doi.org/10.1016/j.neuron.2009.08.037

Möcks, J. (1986). The influence of latency jitter in principal component analysis of event-related potentials. *Psychophysiology*, *23*(4), 480–484. https://doi.org/10.1111/j.1469-8986.1986.tb00659.x

Mørup, M., Madsen, K. H., & Hansen, L. K. (2007). Shifted independent component analysis. In M. E. Davies, C. J. James, S. A. Abdallah, & M. D. Plumbley (Eds.), *Independent component analysis and signal separation. ICA 2007. Lecture notes in computer science, vol. 4666* (pp. 89–96). Springer.

Mulert, C., Juckel, G., Giegling, I., Pogarell, O., Leicht, G., Karch, S., Mavrogiorgou, P., Möller, H. J., Hegerl, U., & Rujescu, D. (2006). A Ser9Gly polymorphism in the dopamine D3 receptor gene (DRD3) and event-related P300 potentials. *Neuropsychopharmacology*, *31*(6), 1335–1344. https://doi.org/10.1038/sj.npp.1300984

Müller, V., & Anokhin, A. P. (2012). Neural synchrony during response production and inhibition. *PloS One*, *7*(6), Article e38931.

https://doi.org/10.1371/journal.pone.0038931

Muller-Gass, A., Macdonald, M., Schröger, E., Sculthorpe, L., & Campbell, K. (2007). Evidence for the auditory P3a reflecting an automatic process: Elicitation during highly-focused continuous visual attention. *Brain Research, 1170*, 71–78. https://doi.org/10.1016/j.brainres.2007.07.023

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology*, *24*(4), 375–425. https://doi.org/10.1111/j.1469-8986.1987.tb00311.x

Nakata, H., Sakamoto, K., Ferretti, A., Gianni Perrucci, M., Del Gratta, C., Kakigi, R., & Luca Romani, G. (2009). Negative BOLD effect on somato-motor inhibitory processing: an fMRI study. *Neuroscience Letters*, *462*(2), 101–104. https://doi.org/10.1016/j.neulet.2009.06.088

Nakata, H., Sakamoto, K., Ferretti, A., Gianni Perrucci, M., Del Gratta, C., Kakigi, R., & Luca Romani, G. (2008a). Somato-motor inhibitory processing in humans: an event-related functional MRI study. *NeuroImage*, *39*(4), 1858–1866. https://doi.org/10.1016/j.neuroimage.2007.10.041

Nakata, H., Sakamoto, K., Ferretti, A., Gianni Perrucci, M., Del Gratta, C., Kakigi, R., & Romani, G. L. (2008b). Executive functions with different motor outputs in somatosensory Go/Nogo tasks: an event-related functional MRI study. *Brain Research Bulletin*, *77*(4), 197–205. https://doi.org/10.1016/j.brainresbull.2008.07.008

Nakata, H., Sakamoto, K., & Kakigi, R. (2012). The relationship between reaction time and response variability and somatosensory No-go potentials. *European Journal of Applied Physiology*, *112*(1), 207–214. https://doi.org/10.1007/s00421-011-1973-5

Nandam, L. S., Hester, R., Wagner, J., Dean, A. J., Messer, C., Honeysett, A., Nathan, P. J., & Bellgrove, M. A. (2013). Dopamine D_2 receptor modulation of human response inhibition and error awareness. *Journal of Cognitive Neuroscience*, *25*(4), 649–656. https://doi.org/10.1162/jocn_a_00327

Nguyen, A. T., Albrecht, M. A., Lipp, O. V., & Marinovic, W. (Preprint). Motor output matters: evidence of a continuous relationship between stop/No-go P300 amplitude and response force on failed inhibitions at the Trial-Level. *bioRxiv*, Article 706978. https://doi.org/10.1101/706978

Nieoullon, A. (2002). Dopamine and the regulation of cognition and attention. *Progress in Neurobiology*, *67*(1), 53–83. https://doi.org/10.1016/S0301-0082(02)00011-4

Noudoost, B., & Moore, T. (2011). The role of neuromodulators in selective attention. *Trends in Cognitive Sciences*, *15*(12), 585–591. https://doi.org/10.1016/j.tics.2011.10.006

Ogrim, G., & Hestad, K. A. (2013). Effects of neurofeedback versus stimulant medication in attention-deficit/hyperactivity disorder: A randomized pilot study. *Journal of Child and*

Adolescent Psychopharmacology, 23(7), 448–457. https://doi.org/10.1089/cap.2012.0090

Ohbayashi, W., Kakigi, R., & Nakata, H. (2017). Effects of white noise on event-related potentials in somatosensory Go/No-go paradigms. *NeuroReport, 28*(13), 788–792. https://doi.org/10.1097/WNR.0000000000000821

Okugawa, H., Ueda, R., Matsumoto, K., Kawanishi, K., & Kato, K. (2000). Effects of sesquiterpenoids from "Oriental incenses" on acetic acid-induced writhing and D2 and 5-HT2A receptors in rat brain. *Phytomedicine*, *7*(5), 417–422. https://doi.org/10.1016/S0944-7113(00)80063-X

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*(1), 97–113.

Ouyang, G., Herzmann, G., Zhou, C., & Sommer, W. (2011). Residue iteration decomposition (RIDE): A new method to separate ERP components on the basis of latency variability in single trials. *Psychophysiology, 48*(12), 1631–1647. https://doi.org/10.1111/j.1469-8986.2011.01269.x

Pascual-Marqui, R. D. (1999). Review of methods for solving the EEG inverse problem. *International Journal of Bioelectromagnetism*, *1*(1), 75–86.

Pascual-Marqui, R. D. (2002). Standardised low resolution brain electromagnetic tomography (sLORETA): technical details. *Methods & Findings in Experimental & Clinical Pharmacology*, *24* (Suppl. D), 5–12.

Pascual-Marqui, R. D. (2007). Discrete, 3D distributed, linear imaging methods of electric neuronal activity. Part 1: Exact, zero error localization. *arXiv.* https://arxiv.org/abs/0710.3341

Pascual-Marqui, R. D. (2009). Theory of the EEG inverse problem. In S. Tong & N. V. Thakor (Eds.), *Quantitative EEG Analysis: Methods and Clinical Applications* (pp. 121–140). Artech House.

Peterson, B. S., Kane, M. J., Alexander, G. M., Lacadie, C., Skudlarski, P., Leung, H. C., May, J., & Gore, J. C. (2002). An event-related functional MRI study comparing interference effects in the Simon and Stroop tasks. *Cognitive Brain Research, 13*(3), 427–440. https://doi.org/10.1016/S0926-6410(02)00054-X

Peterson, B. S., Skudlarski, P., Gatenby, J. C., Zhang, H., Anderson, A. W., & Gore, J. C. (1999). An fMRI study of Stroop word color interference: evidence for cingulate subregions subserving multiple distributed attentional systems. *Biological Psychiatry, 45*(10), 1237–1258. https://doi.org/10.1016/S0006-3223(99)00056-6

Pfefferbaum, A., Ford, J. M., Weller, B. J., & Kopell, B. S. (1985). ERPs to response production and inhibition. *Electroencephalography and Clinical Neurophysiology, 60*(5), 423–434. http://doi.org/10. 1016/0013-4694(85)91017-X

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., Jr., Miller, G. A., Ritter, W., Ruchkin, D. S., Rugg, M. D., & Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, *37*(2), 127–152. https://doi.org/10.1111/1469-8986.3720127

Piispala, J., Kallio, M., Bloigu, R., & Jansson-Verkasalo, E. (2016). Delayed N2 response in Go condition in a visual Go/Nogo ERP study in children who stutter. *Journal of Fluency Disorders*, *48*, 16–26. https://doi.org/10.1016/j.jfludis.2016.02.001

Piispala, J., Määttä, S., Pääkkönen, A., Bloigu, R., Kallio, M., & Jansson-Verkasalo, E. (2017). Atypical brain activation in children who stutter in a visual Go/Nogo task: An ERP study. *Clinical Neurophysiology*, *128*(1), 194–203. https://doi.org/10.1016/j.clinph.2016.11.006

Pires, L., Leitão, J., Guerrini, C., & Simões, M. R. (2014). Event-related brain potentials in the study of inhibition: Cognitive control, source localisation and age-related modulations. *Neuropsychology Review*, *24*(4), 461–490. http://doi.org/10.1007/s11065-014-9275-4

Poli, R., Cinel, C., Citi, L., & Sepulveda, F. (2010). Reaction-time binning: A simple method for increasing the resolving power of ERP averages. *Psychophysiology*, *47*(3), 467–485. https://doi.org/10.1111/j.1469-8986.2009.00959.x

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*(10), 2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Polich, J., & Criado, J. R. (2006). Neuropsychology and neuropharmacology of P3a and P3b. *International Journal of Psychophysiology*, *60*(2), 172–185. https://doi.org/10.1016/j.ijpsycho.2005.12.012

Pscherer, C., Mückschel, M., Summerer, L., Bluschke, A., & Beste, C. (2019). On the relevance of EEG resting theta activity for the neurophysiological dynamics underlying motor inhibitory control. *Human Brain Mapping*, *40*(14), 4253–4265. https://doi.org/10.1002/hbm.24699

Purves, D., Augustine, G. J., Fitzpatrick, D., Katz, L. C., LaMantia, A., McNamara, J. O., & Williams, S. M. (2001). *Neuroscience* (2nd ed.). Sinauer Associates.

Randall, W. M., & Smith, J. L. (2011). Conflict and inhibition in the cued-Go/NoGo task. *Clinical Neurophysiology*, *122*(12), 2400–2407. https://doi.org/10.1016/j.clinph.2011.05.012

Rausch, V. H., Bauch, E. M., & Bunzeck, N. (2014). White noise improves learning by modulating activity in dopaminergic midbrain regions and right superior temporal sulcus. *Journal of Cognitive Neuroscience*, *26*(7), 1469–1480. https://doi.org/10.1162/jocn_a_00537

Recio, G., Schacht, A., & Sommer, W. (2009). Effects of inter-stimulus interval on skin conductance responses and event-related potentials in a Go/NoGo task. *Biological*

Psychology, *80*(2), 246–250. https://doi.org/10.1016/j.biopsycho.2008.10.007

Roberts, L. E., Rau, H., Lutzenberger, W., & Birbaumer, N. (1994). Mapping P300 waves onto inhibition: Go/No-Go discrimination. *Electroencephalography and Clinical Neurophysiology*, *92*(1), 44–55. https://doi.org/10.1016/0168-5597(94)90006-x

Robertson, C. L., Ishibashi, K., Mandelkern, M. A., Brown, A. K., Ghahremani, D. G., Sabb, F., Bilder, R., Cannon, T., Borg, J., & London, E. D. (2015). Striatal D1- and D2-type dopamine receptors are linked to motor response inhibition in human subjects. *The Journal of Neuroscience*, *35*(15), 5990–5997. https://doi.org/10.1523/JNEUROSCI.4850-14.2015

Rubia, K., Russell, T., Overmeyer, S., Brammer, M. J., Bullmore, E. T., Sharma, T., Simmons, A., Williams, S. C., Giampietro, V., Andrew, C. M., & Taylor, E. (2001). Mapping motor inhibition: Conjunctive brain activations across different versions of go/no-go and stop tasks. *NeuroImage*, *13*(2), 250–261. http://doi.org/10.1006/nimg.2000.0685

Ruchsow, M., Groen, G., Kiefer, M., Buchheim, A., Walter, H., Martius, P., Reiter, M., Hermle, L., Spitzer, M., Ebert, D., & Falkenstein, M. (2008). Response inhibition in borderline personality disorder: Event-related potentials in a Go/Nogo task. *Journal of Neural Transmission*, *115*(1), 127–133. https://doi.org/10.1007/s00702-007-0819-0

Rushworth, M. F. S., Walton, M. E., Kennerley, S. W., & Bannerman, D. M. (2004). Action sets and decisions in the medial frontal cortex. *Trends in Cognitive Sciences*, *8*(9), 410–417. https://doi.org/10.1016/j.tics.2004.07.009

Rupp, C. I., Beck, J. K., Heinz, A., Kemmler, G., Manz, S., Tempel, K., & Fleischhacker, W. W. (2016). Impulsivity and Alcohol Dependence Treatment Completion: Is There a Neurocognitive Risk Factor at Treatment Entry?. *Alcoholism, Clinical and Experimental Research*, *40*(1), 152–160. https://doi.org/10.1111/acer.12924

Sams, M., Alho, K., & Näätänen, R. (1983). Sequential effects on the ERP in discriminating two stimuli. *Biological Psychology*, *17*(1), 41–58. https://doi.org/10.1016/0301-0511(83)90065-0

Saville, C. W. N., Dean, R. O., Daley, D., Intriligator, J., Boehm, S., Feige, B., & Klein, C. (2011). Electrocortical correlates of intra-subject variability in reaction times: Average and single-trial analyses. *Biological Psychology*, *87*(1), 74–83. https://doi.org/10.1016/j.biopsycho.2011.02.005

Schacht, A., Nigbur, R., & Sommer, W. (2009). Emotions in Go/NoGo conflicts. *Psychological Research*, *73*(6), 843–856. https://doi.org/10.1007/s00426-008-0192-0

Scharf, F., & Nestler, S. (2018a). Exploratory structural equation modelling for event-related potential data—An all-in-one approach? *Psychophysiology*, *56*(3), 1–19. https://doi.org/10.1111/psyp.13303

Scharf, F., & Nestler, S. (2018b). Principles behind variance misallocation in temporal

exploratory factor analysis for ERP data: Insights from an inter-factor covariance decomposition. *International Journal of Psychophysiology*, *128*, 119–136. https://doi.org/10.1016/j.ijpsycho.2018.03.019

Scharf, F., & Nestler, S. (2019). A comparison of simple structure rotation criteria in temporal exploratory factor analysis for event-related potential data. *Methodology*, 15, 43–60. https://doi.org/10.1027/1614-2241/a000175

Schmajuk, M., Liotti, M., Busse, L., & Woldorff, M. G. (2006). Electrophysiological activity underlying inhibitory control processes in normal adults. *Neuropsychologia*, *44*(3), 384–395. https://doi.org/10.1016/j.neuropsychologia.2005.06.005

Schoenberg, P. L. A., Hepark, S., Kan, C. C., Barendregt, H. P., Buitelaar, J. K., & Speckens, A. E. M. (2014). Effects of mindfulness-based cognitive therapy on neurophysiological correlates of performance monitoring in adult attention-deficit/hyperactivity disorder. *Clinical Neurophysiology*, *125*(7), 1407–1416. https://doi.org/10.1016/j.clinph.2013.11.031

Seo, D., Patrick, C. J., & Kennealy, P. J. (2008). Role of serotonin and dopamine system interactions in the neurobiology of impulsive aggression and its comorbidity with other clinical disorders. *Aggression and Violent Behavior*, *13*(5), 383–395. https://doi.org/10.1016/j.avb.2008.06.003

Shubotz, R. I., & von Cramon, D. Y. (2002). A blueprint for target motion: fMRI reveals perceived sequential complexity to modulate premotor cortex. *NeuroImage*, *16*(4), 920–935. https://doi.org/10.1006/nimg.2002.1183

Smith, J. L., Johnstone, S. J., & Barry, R. J. (2008). Movement-related potentials in the Go/NoGo task: The P3 reflects both cognitive and motor inhibition. *Clinical Neurophysiology*, *119*(3), 704–714. http://doi.org/10.1016/j.clinph.2007.11.042

Smith, J. L., Smith, E. A., Provost, A. L., & Heathcote, A. (2010). Sequence effects support the conflict theory of N2 and P3 in the Go/NoGo task. *International Journal of Psychophysiology*, *75*(3), 217–226. https://doi.org/10.1016/j.ijpsycho.2009.11.002

Smith, L. J., Henderson, J. A., Abell, C. W., & Bethea, C. L. (2004). Effects of ovarian steroids and raloxifene on proteins that synthesize, transport, and degrade serotonin in the raphe region of macaques. *Neuropsychopharmacology*, *29*(11), 2035–2045. https://doi.org/10.1038/sj.npp.1300510

Smulders, F. T. Y., & Miller, J. O. (2012). The lateralized readiness potential. In S. J. Luck & E. S. Kappenman (Eds.), *The Oxford handbook of event-related potential components* (pp. 209–229). Oxford University Press.

Spencer, K. M. (2005). Averaging, detection, and classification of single-trial ERPs. In T. C. Handy (Ed.), *Event Related Potentials. A Methods Handbook* (pp. 209–228). MIT Press.

Spencer, K. M., Abad, E. V., & Donchin, E. (2000). On the search for the neurophysiological manifestation of recollective experience. *Psychophysiology*, *37*(4), 494–506. https://doi.org/10.1111/1469-8986.3740494

Spencer, K. M., & Polich, J. (1999). Poststimulus EEG spectral analysis and P300: attention, task and probability. *Psychophysiology*, *36*(2), 220–232. https://doi.org/10.1111/1469-8986.3620220

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology*, *38*(4), 387–401. https://doi.org/10.1016/0013-4694(75)90263-1

Takahashi, H., Rissling, A. J., Pascual-Marqui, R., Kirihara, K., Pela, M., Sprock, J., Braff, D. L., & Light, G. A. (2014). Neural substrates of normal and impaired preattentive sensory discrimination in large cohorts of nonpsychiatric subjects and schizophrenia patients as indexed by MMN and P3a change detection responses. *NeuroImage*, *66*, 594–603. https://doi.org/10.1016/j.neuroimage.2012.09.074

Takeshita, S., & Ogura, C. (1994). Effect of the dopamine D2 antagonist sulpiride on event-related potentials and its relation to the law of initial value. *International Journal of Psychophysiology*, *16*(1), 99–106. https://doi.org/10.1016/0167-8760(94)90046-9

Talati, A., & Hirsch, J. (2005). Functional specialization within the medial frontal gyrus for perceptual go/no-go decisions based on "what," "when," and "where" related information: An fMRI study. *Journal of Cognitive Neurocience*, *17*(7), 981–993. https://doi.org/10.1162/0898929054475226

Thornton, A. R. D. (2008). Evaluation of a technique to measure latency jitter in event-related potentials. *Journal of Neuroscience Methods*, *168*(1), 248–255. https://doi.org/10.1016/j.jneumeth.2007.09.031

Thornton, E. W., & Goudie, A. J. (1978). Evidence for the role of serotonin in the inhibition of specific motor responses. *Psychopharmacology*, *60*(1), 73–79. https://doi.org/10.1007/BF00429182

Trongnetrpunya, A., Rapp, P., Wang, C., Darmon, D., Costanzo, M. E., Nathan, D. E., Roy, M. J., Cellucci, C. J., & Keyser, D. (2019). Single-trial mechanisms underlying changes in averaged P300 ERP amplitude and latency in military service members after combat deployment. *Frontiers in Human Neuroscience*, *13*, 1–11. https://doi.org/10.3389/fnhum.2019.00377

Truccolo, W. A., Ding, M., Knuth, K. H., Nakamura, R., & Bressler, S. L. (2002). Trial-to-trial variability of cortical evoked responses: Implications for the analysis of functional connectivity. *Clinical Neurophysiology*, *113*(2), 206–226. https://doi.org/10.1016/S1388-2457(01)00739-8

Tuan, P. D., Möcks, J., Köhler, W., & Gasser, T. (1987). Variable latencies of noisy signals: Estimation and testing in brain potential data. *Biometrika, 74*(3), 525–533. https://doi.org/10.1093/biomet/74.3.525

Ullsperger, M., Danielmeier, C., & Jocham, G. (2014). Neurophysiology of performance monitoring and adaptive behavior. *Physiological Reviews, 94*(1), 35–79. https://doi.org/10.1152/physrev.00041.2012

Vallesi A. (2011). Targets and non-targets in the aging brain: A go/nogo event-related potential study. *Neuroscience Letters, 487*(3), 313–317. https://doi.org/10.1016/j.neulet.2010.10.046

Verleger, R., Grauhan, N., & Śmigasiewicz, K. (2016). Is P3 a strategic or a tactical component? Relationships of P3 sub-components to response times in oddball tasks with go, no-go and choice responses. *NeuroImage, 143,* 223–234. https://doi.org/10.1016/j.neuroimage.2016.08.049

Verleger, R., Jaśkowski, P., & Wascher, E. (2005). Evidence for an integrative role of P3b in linking reaction to perception. *Journal of Psychophysiology, 19*(3), 165–181. https://doi.org/10.1027/0269-8803.19.3.165

Vogel, C. I., Laucht, M., Furtado, E. F., Becker, K., & Schmidt, M. H. (2006). Association of DRD4 exon III polymorphism with auditory P300 amplitude in 8-year-old children. *Journal of Neural Transmission, 113*(12), 1935–1941. https://doi.org/10.1007/s00702-006-0497-3

Volkow, N. D., Wang, G. J., Logan, J., Alexoff, D., Fowler, J. S., Thanos, P. K., Wong, C., Casado, V., Ferre, S., & Tomasi, D. (2015). Caffeine increases striatal dopamine D2/D3 receptor availability in the human brain. *Translational Psychiatry, 5*(4), Article e549. https://doi.org/10.1038/tp.2015.46

Volpe, U., Mucci, A., Bucci, P., Merlotti, E., Galderisi, S., & Maj, M. (2007). The cortical generators of P3a and P3b: A LORETA study. *Brain Research Bulletin, 12*(4–6), 220–230. https://doi.org/10.1016/j.brainresbull.2007.03.003

Volpert-Esmond, H. I., Merkle, E. C., Levsen, M. P., Ito, T. A., & Bartholow, B. D. (2018). Using trial-level data and multilevel modeling to investigate within-task change in event-related potentials. *Psychophysiology, 55*(5), Article e13044. https://doi.org/10.1111/psyp.13044

Vossen, H., Van Breukelen, G., Hermens, H., Van Os, J., & Lousberg, R. (2011). More potential in statistical analyses of event-related potentials: A mixed regression approach. *International Journal of Methods in Psychiatric Research, 20*(3), 56–68. https://doi.org/10.1002/mpr.348

Walhovd, K. B., Rosquist, H., & Fjell, A. M. (2008). P300 amplitude age reductions are not cause by latency jitter. *Psychophysiology, 45*(4), 545–553.

https://doi.org/10.1111/j.1469-8986.2008.00661.x

Watanabe, J., Sugiura, M., Sato, K., Sato, Y., Maeda, Y., Matsue, Y., Fukuda, H., & Kawashima, R. (2002). The human prefrontal and parietal association cortices are involved in NO-GO performances: an event-related fMRI study. *NeuroImage, 17*(3), 1207–1216. https://doi.org/10.1006/nimg.2002.1198

Wessel, J. R. (2018a). Prepotent motor activity and inhibitory control demands in different variants of the go/no-go paradigm. *Psychophysiology, 55*(3), Article e12871. https://doi.org/10.1111/psyp.12871

Wessel, J. R. (2018b). Testing Multiple Psychological Processes for Common Neural Mechanisms Using EEG and Independent Component Analysis. *Brain Topography, 31*(1), 90–100. https://doi.org/10.1007/s10548-016-0483-5

Wong, P. T., Feng, H., & Teo, W. L. (1995). Interaction of the dopaminergic and serotonergic systems in the rat striatum: effects of selective antagonists and uptake inhibitors. *Neuroscience Research, 23*(1), 115–119. https://doi.org/10.1016/0168-0102(95)90023-3

Woodward, T. S., Ruff, C. C., & Ngan, E. T. C. (2006). Short- and long-term changes in anterior cingulate activation during resolution of task-set competition. *Brain Research, 1068*(1), 161–169. https://doi.org/10.1016/j.brainres.2005.10.094

Woody, C. D. (1967). Characterization of an adaptive filter for the analysis of variable latency neuroelectric signals. *Medical and Biological Engineering, 5*(6), 539–553. https://doi.org/10.1016/j.synthmet.2005.05.016

Wronka, E., Kaiser, J., & Coenen, A. M. L. (2012). Neural generators of the auditory evoked potential components P3a and P3b. *Acta Neurobiologiae Experimentalis, 72*, 51–64.

Wu, J., Yuan, Y., Cao, C., Zhang, K., Wang, L., & Zhang, L. (2015). The relationship between response inhibition and posttraumatic stress symptom clusters in adolescent earthquake survivors: an event-related potential study. *Scientific Reports, 5*, Article 8844. https://doi.org/10.1038/srep08844

Yamanaka, K., & Yamamoto, Y. (2010). Single-trial EEG power and phase dynamics associated with voluntary response inhibition. *Journal of Cognitive Neuroscience, 22*(4), 714–727. https://doi.org/10.1162/jocn.2009.21258

Yang, B., Yang, S., Zhao, L., Yin, L., Liu, X., & An, S. (2009). Event-related potentials in a Go/Nogo task of abnormal response inhibition in heroin addicts. *Science in China. Series C, Life Sciences, 52*(8), 780–788. https://doi.org/10.1007/s11427-009-0106-4

Yang, L., Xu, Q., Li, S., Zhao, X., Ma, L., Zheng, Y., Zhang, J., & Li, Y. (2015). The effects of methadone maintenance treatment on heroin addicts with response inhibition function impairments: Evidence from event-related potentials. *Journal of Food and Drug Analysis, 23*(2), 260–266. https://doi.org/10.1016/j.jfda.2014.06.002

Yao, J., & Dewald, J. P. (2005). Evaluation of different cortical source localization methods using simulated and experimental EEG data. *NeuroImage*, *25*(2), 369–382. https://doi.org/10.1016/j.neuroimage.2004.11.036

Yan-ling, R., & Xuan, D. (2013). Effects of methylphenidate in children with attention deficit hyperactivity disorder: A comparison of behavioral results and event–related potentials. In S. Banerjee (Ed.), *Attention deficit hyperactivity disorder in children and adolescents* (pp. 181–191). IntechOpen.

Ye, Z., Altena, E., Nombela, C., Housden, C. R., Maxwell, H., Rittman, T., Huddleston, C., Rae, C. L., Regenthal, R., Sahakian, B. J., Barker, R. A., Robbins, T. W., & Rowe, J. B. (2014). Selective serotonin reuptake inhibition modulates response inhibition in Parkinson's disease. *Brain*, *137*(Pt 4), 1145–1155. https://doi.org/10.1093/brain/awu032

Yordanova, J., & Kolev, V. (1998). Event-related alpha oscillations are functionally associated with P300 during information processing. *NeuroReport*, *9*(14), 3159–3164. https://doi.org/10.1097/00001756-199810050-00007

Zhang, B. W., Xu, J., & Chang, Y. (2016). The effect of aging in inhibitory control of major depressive disorder revealed by event-related potentials. *Frontiers in Human Neuroscience*, *10,* Article 116. https://doi.org/10.3389/fnhum.2016.00116

Chapter 6. General Discussion

The purpose of this thesis was to elucidate the functional significance of the ERP/PCA components associated with auditory Go/NoGo tasks and to clarify the cognitive and behavioural processing requirements in simple *equiprobable* Go/NoGo variants. For that purpose, four empirical studies were conducted to clarify how auditory Go/NoGo ERP/PCA components relate to cognitive and behavioural processing in healthy young adults under different Go/NoGo task conditions. The four studies aimed to promote psychophysiological theory development by providing detailed insight into the functional and/or structural characteristics of common and novel ERP components. In this final chapter, the major study outcomes are discussed and integrated into an updated sequential processing schema to synthesise the current thesis outcomes in an intuitive manner that delineates our improved conceptualisation of auditory equiprobable Go/NoGo processing in healthy young adults.

Studies 1 and 2 manipulated Go/NoGo stimulus probability to alter cognitive task demands within subjects and compare the equiprobable task processing series with that in the classic oddball and traditional 'frequent Go' tasks. This was deemed to be important considering that only a few limited studies have formally compared the broader Go and NoGo ERP component series between tasks (as discussed in Chapters 1 and 2: Banquet et al., 1981; Brigham et al., 1995; Duncan-Johnson & Donchin, 1977; Polich et al., 1994; Polich & Margala, 1997; Spencer & Polich, 1999; N. Squires et al., 1975), and even fewer have utilised temporal PCA or other methods of blind signal separation to examine probability effects on ERP components (and subcomponents) relative to simple equiprobable tasks (Duncan-Johnson & Donchin, 1982; N. Squires et al., 1975). This approach was expected to provide a holistic view of task differences, clarify the relationship between the Go/NoGo and oddball ERP literatures, and encourage ERP theory development across simple Go/NoGo tasks.

Study 1 demonstrated that highly similar (almost equivalent) series of ERP components were associated with successful equiprobable and oddball task processing, suggesting that the cognitive requirements in those tasks were almost identical for healthy young adults. This provides strong support for the generalisability of the Sequential Processing Schema, and in a broader sense, the extrapolation and integration of ERP outcomes from both equiprobable and oddball tasks. Study 1 was the first systematic within-subject comparison of the ERP component processing series between these tasks using *separate* PCAs, allowing the factors to reflect task- and condition-specific ERP variance rather than forcibly extracting a composite factor solution across multiple conditions; it also utilised a higher sample size and temporal/spatial resolution, so the outcomes are considered to be more robust and sensitive to potential task ERP differences than the probability research cited above. The Go/NoGo probability effects on ERP components were generally consistent with prior research (summarised in Chapter 2 and below), and the PCA factor series were similar to those in N. Squires et al. (1975) and Duncan-Johnson and Donchin (1977); although Study 1 analysed a more-complete ERP component series.

Study 1 also indicated the existence of two distinguishable Go and NoGo SW components in each task (i.e., SW1 and SW2), corroborating two-choice task research suggesting that the late SW involves several subcomponents (e.g., Borchard et al., 2015; Fitzgerald & Picton, 1981; Karamacoska et al., 2018; Näätänen et al., 1982); although it is not yet clear whether SW1 or SW2 reflect subcomponents of the classic SW, or other slow potentials, such as the reafferent potential or contingent negative variation (e.g., Bötzel et al., 1997; Desmedt & Debecker, 1979; Di Russo et al., 2017; Friedman, 1984; García-Larrea & Cézanne-Bert, 1998; Kornhuber & Deecke, 2016; Rohrbaugh et al., 1978; Ruchkin et al., 1988, 1990, 1995; Shibasaki et al., 1980; Vaughan et al., 1968). The characterisation of SW1 and SW2 in Study 1 has since guided their identification and interpretation in subsequent studies using other samples (Barry et al., 2019; Fogarty et al., 2020a), indicating that the two components are reliable factors in the Varimax rotated auditory Go/NoGo ERP processing series.

The identification of the hemispheric PCA-derived Processing Negativity (PN) associated with auditory Go/NoGo processing in the Schema (e.g., Barry & De Blasio, 2013; Fogarty et al., 2019) was also questioned in Study 1. The presence of PN has important implications for Go/NoGo task processing considering its link to higher order 'proactive' information processes (e.g., the use/maintenance of an attentional trace: Näätänen, 1982). Hence, Study 2 aimed to clarify the identity of "PN" in auditory equiprobable and 'frequent Go' tasks using temporal PCA and traditional PN measures (i.e., difference waveforms). The typical hemispheric negativity was extracted, but as expected, the study demonstrated that it was a better match for the exogenous N1c. In essence, no PN was found in young adults, confirming the component-labelling error in the initial Schema-related studies of young adults (see Barry et al., 2014a, 2014a, 2016a, 2016b, 2020; Barry & De Blasio, 2013; Borchard et al., 2015; Fogarty et al., 2018, 2019).

Paralleling Study 1, Study 2 demonstrated that the early auditory ERP processing series in the equiprobable and 'frequent Go' tasks were highly comparable; hence, following the improvements to the characterisation of the N1 components in Study 2, it can be concluded that the three Go/NoGo variants in this thesis shared similar early processing requirements, marked by P1, N1a, N1b, N1c, and either Go P2 or NoGo N2b. Using PCAs to identify these components in Studies 1 and 2 has provided a stronger definition of their temporal and topographic features, as well as their cortical sources; this is particularly important for the three 'true' N1 components, which are often overlooked in psychophysiological research, perhaps because they are difficult to separate with traditional ERP measures. The ability to extract these true N1 components separately demonstrates their important role in Go/NoGo processing, as well as the utility of PCA and this task for studying cognitive difficulties that may be marked by specific N1 components, and other processes indexed by later components (e.g., dyslexia or schizophrenia; see McCarley et al., 1991; Taylor et al., 2003).

Studies 3 and 4 explored equiprobable Go/NoGo ERP/PCA component functionality further. Importantly, Study 3 confirmed that N1b, N1c, and P2 were related to stimulus processing (as suggested in previous research, e.g., Burkhard et al., 2019; Crowley & Colrain, 2004; Lijffijt et al., 2009; Näätänen & Picton, 1987), and demonstrated that Go P3b, SW1, and SW2 were primarily response-locked (corroborating traditional ERP findings in similar tasks: Berchicci et al., 2016; Falkenstein et al., 1991; Goodin et al., 1986). Study 4 indicated that NoGo P3a was not related to inhibitory demands or NoGo performance, and suggested that healthy young adults generally do not require effortful motor inhibition in auditory equiprobable NoGo trials (Barry & Rushby, 2006; Wessel, 2018). As discussed in Studies 3 and 4, these outcomes have significant implications for the utility of equiprobable Go/NoGo tasks (e.g., for inhibition research), and for the conceptualisation and application of ERP components that are frequently studied in psychophysiology. Primarily, equiprobable tasks are not practical for studying motor inhibition in healthy young adults (Wessel, 2018), contrary to the suggestion that individuals may still need active response inhibition in these tasks (*cf.* Boulinguez et al., 2009; Criaud & Boulinguez, 2013; Donkers & Van Boxtel, 2004).

1.1. P1 and N1: implications for early Go/NoGo processing

The temporal PCA outcomes in Studies 1–4 clarified the ERP component series in auditory Go/NoGo tasks, showing that healthy young adults exhibit a frontal P1 that peaks approximately 50 ms after stimulus onset, followed by a large N1 complex, featuring three 'true' or exogenous N1 subcomponents: a central (and somewhat parietal) N1a peaking approximately 75 ms poststimulus, a large frontocentral N1b that peaks around 120 ms poststimulus, and a temporal N1c approximately 150 ms poststimulus (consistent with McCallum & Curry, 1980; Näätänen & Picton, 1987; Woods, 1995). These P1 and N1 components were evident in both the Go and NoGo processing chains, suggesting that they mark fundamental auditory processing requirements (Garcia-Larrea et al., 1992; Näätänen & Picton, 1987; Schröger et al., 2015).

The significant variations in P1 and N1 component amplitudes related to stimulus type and probability in Studies 1 and 2 (and traditional ERP research: Ko et al., 2012; Polich et al., 1994; Polich & Margala, 1997; Spencer & Polich, 1999) demonstrated that different Go and NoGo trial demands can occur in these common processing stages, and that stimulus-specific information is registered early in the Go/NoGo processing sequence, perhaps even at low- or sub-conscious levels (Jerger et al., 1992; Lijffijt et al., 2009).

The early stimulus effects shown in Studies 1 and 2 were considered to corroborate previous studies linking variations in P1 and N1 amplitudes to selective attention (Hillyard, 1998; Hillyard et al., 1973; Johannes et al., 1995; Näätänen, 1982, 1988, 1990; Schröger et al., 2015; Wijers et al., 1997), the ability to distinguish relevant stimulus input from noise, in order to facilitate further processing (Joos et al., 2014; Lijffijt et al., 2009). Notably, this thesis did not support the Attentional Trace Theory of selective attention, given the absence of MMN and a true

PN in Experiments 1 and 2 (*cf.* Näätänen, 1982). Instead, the current findings are perhaps best explained by sensory gain control (or gating), a proposed mechanism of selective attention involving the early filtering of sensory input via selective inhibition and/or amplification of sensory-evoked responses in the cortex (Hillyard, 1998; Hillyard & Mangun, 1987; Lijffijt et al., 2009).

From that viewpoint, the PCA-derived P1 and N1 components (i.e., N1a, N1b, N1c) can be considered to represent a complex interaction between bottom-up sensory processes and top-down executive control functions (e.g., Knight et al., 1989, 1995). This account is supported by Study 3 which confirmed that N1b and N1c were primarily related to sensory processing; as well as the complex cortical sources underpinning the P1 and N1 components in Study 2, which can be considered to reflect an ongoing relationship between sensory processes and a core executive network (involving BAs 6, 8, 9, 10, and 11).

P1 was related to activity in areas linked to cognitive control, memory retrieval, and the orienting of attention (e.g., Catalan et al., 1998; Mayer et al., 2006; Peterson & Posner, 2012; Tsukiura et al., 2001), indicating that it could reflect brain activity that facilitates a consequent stimulus-driven shift in attention (Corbetta & Shulman, 2002). From this viewpoint, P1 might be related to processing that has often been attributed to N1, such as the triggering of attention or the onset of stimulus categorisation; though it may not reflect those processes per se.

P1 was not related to activity in cortical areas specifically associated with auditory processing (Fogarty et al., 2020b). Thus, it could reflect an initial shift in cortical arousal that facilitates active processing marked by subsequent components (e.g., N1). In keeping with that, and a gain control account, the frontally positive and centroparietally negative topography of P1 could be considered to reflect frontal inhibitory control of stimulus processing (i.e., sensory gating) and activation in the parietal cortex, facilitating the orienting of attention and/or memory processing.

The Go/NoGo N1a, N1b, and N1c components identified in this thesis increased in amplitude as stimulus probability decreased, corroborating broader findings associated with the N1 wave (Ko et al., 2012; Polich et al., 1994; Polich & Margala, 1997; Spencer & Polich, 1999). Together, these effects are consistent with refractory effects identified for N1 (e.g., Budd et al., 1998; Coch et al., 2005; Nelson & Lassman, 1968, 1973, 1977; Pereira et al., 2014; Steiner et al., 2014b, 2016), but could also indicate a shift in the demand on fundamental auditory information processes associated with the frequency of stimulus presentation, implying that the processes underlying N1 can be sensitive to implicit learning or neuronal adaptation across trials (e.g., Elvira et al., 2003; Kudela et al., 2018; Hermanutz et al., 1981; Steiner et al., 2014a; Verleger, 1987; Zhang et al., 2011). These N1 probability effects are compatible with sensory gain control (and predictive coding views) if lower probability stimuli are considered to demand more attention or

effort relative to predictable stimuli (Hillyard, 1998; Marzecová et al., 2017; Schröger et al., 2015; Starr et al., 1997; Steiner et al., 2014b).

The eLORETA source solutions for N1a, N1b, and N1c in Study 2 demonstrated a substantial role of the temporal cortex (BAs 21, 22, 38, and 41) and primary motor cortex (BA 4) in the processing stages following P1. The temporal sources here are consistent with established accounts relating N1components to auditory processing (Näätänen & Picton, 1987). However, N1 activation in the primary motor cortex and the core frontal sources also implies that higher-level cognitive processes could interact with the auditory processing in the temporal cortices. These outcomes are compatible with research linking N1 to stimulus categorisation (Borchard et al., 2015), decisional processes (Filipović et al., 2000), or the activation of learned stimulus-response associations (Bender et al., 2006); which could follow early memory processing related to P1 (i.e., in the precuneus: Catalan et al., 1998; Tsukiura et al., 2001). Study 3 corroborates the suggested relationship between N1 and stimulus-response processing, by linking the stimulus-specific N1c and Go RTs, similar to previous N1 findings (Steiner et al., 2016).

1.2. P2, N2, P3, and SW: implications for further Go/NoGo processing

Different Go and NoGo ERP/PCA processing chains were evident after P1 and N1 (Barry et al., 2016, 2018, 2019; Fogarty et al., 2019, 2020b). Studies 1–3 demonstrated that successful Go processing after N1 is marked (in latency order) by a central P2, a minor frontal N2c, a large centroparietal P3b, a centrally positive SW1 and a negative frontoparietal SW2. The response-locked PCA output in Study 3 indicated that the typical (stimulus-locked) Go ERP processing series is also overlapped by unique response-locked ERP components, including a frontal N2 (RN2), a frontocentral negativity identified as a Motor Potential (MP), and a novel parietal positivity labelled P420. In contrast, Studies 1, 2, and 4 indicated that NoGo processing after N1 is marked by a frontal N2b, frontocentral P3a, a frontally-negative SW1 and a centrally positive SW2.

1.2.1. Go ERP components

The PCA-derived Go P2 in this thesis was a stimulus-specific positivity that peaked approximately 220 ms poststimulus at central (and somewhat centroparietal) scalp sites, consistent with the traditional P2 in the broader ERP literature (for a review, see Crowley & Colrain, 2004). P2 was shown in Study 2 to increase with Go stimulus probability (similar to Polich et al., 1994; Spencer & Polich, 1999; N. Squires et al., 1975), which likely explains its absence in the oddball PCA output in Study 1; that is, its amplitude (and thus, attributed ERP variance) was reduced to a point below the extraction threshold of the PCA in the lower Go (target) probability condition (see Chapter 2, Figure 4, p. 42); alternatively, it was not prominent enough to be extracted independently in the Varimax rotated solution.

Little is known about P2 functionality, although it is suggested to relate to stimulus categorisation (Crowley & Colrain, 2004), the rapid activation of perceptual representations in

memory (Tong et al., 2009), or a higher level 'gating' mechanism involving active interference control (i.e., cognitive inhibition) facilitating relevant stimulus-driven processing demanding memory and attention (Lijfijjt et al., 2009; Näätänen, 1992; Nigg, 2000). In addition to the core frontal sources, P2 was associated with activity in the prefrontal cortex (BAs 8, 45 and 47), the anterior cingulate (BAs 24 and 32), and the temporal lobe (BA 22 and 38) in Study 2; which could support its link to auditory stimulus-driven attention and control (Benedict et al., 1998; Cabeza & Nyberg, 1997; Knight et al., 1989, 1995; Nigg, 2000). From a sensory gating perspective, the probability effects on P2 could indicate enhanced or fine-tuned cortical inhibition with the increased repetition of target stimuli, resulting in better interference control to facilitate active stimulus-response processing (e.g., response activation). Greater interference control could also involve rapid access to perceptual representations (or stimulus-response associations) resulting in better task performance (Tong et al., 2009).

A small frontal Go N2c was evident in Study 1 with a peak latency of approximately 260 ms (e.g., Folstein & Van Petten, 2008; Patel & Azzam., 2005; Pritchard et al., 1991; Ritter et al., 1979). That N2c was absent in Study 3, and it was speculated that it had been washed out across the large ERP sample collated for that investigation, due to latency jitter in the stimulus-locked ERP data. This could support the notion that N2c is actually a response-locked ERP component, in keeping with previous evidence linking smaller stimulus-locked N2c amplitudes to greater RT variability (Fogarty et al., 2018). However, no response-locked N2c component was found, unless RN2 is considered as such. Further research is needed to explore the link between RN2 and N2c; until then, the two PCA components are considered to reflect distinct N2 components.

The centroparietal P3b component had a peak-latency around 350 ms poststimulus in Studies 1 and 3, consistent with broader target-P3 research (Conroy & Polich, 2007; Hillyard & Kutas, 1983; Kok, 2004; Patel & Azzam., 2005; Polich, 2007). The Go P3b PCA component was shown to increase as auditory Go probability decreased (Dalbokova et al., 1990; Duncan-Johnson & Donchin, 1982; Fogarty et al., 2019; Hull & Harsh, 2001; Polich et al., 1994; Polich & Margala, 1997; Spencer & Polich, 1999; K. Squires et al., 1977; N. Squires et al., 1975). It was also enhanced in response-locked ERP data (Berchicci et al., 2016; Fogarty et al., 2020a; Goodin et al., 1986), and increased in amplitude as RT variability decreased in Study 3. Together, these outcomes indicate that Go P3b reflects mostly response-related (i.e., response-locked) cognitive processing, which is sensitive to the frequency of the target stimulus (and perhaps the motor response). These findings are compatible with previous studies suggesting that P3 context-updating involves motor (or response) elements (Brydges & Barceló, 2018), consistent with the fact that Go/NoGo task 'contexts' or 'environments' are defined by specific stimulus and motor response relationships; as well as the idea that context-updating determines response processing (i.e., biases or strategies) relative to a working model of the task environment (see Donchin & Coles, 1988; Donchin et al., 1997). Alternatively, these outcomes are also compatible with

suggestions that P3b may be related to the more tactical reactivation of stimulus-response associations, which are considered to be more demanding in rare conditions (Verleger et al., 2014, 2015, 2016).

In Study 3, the P3b and grand mean RT were closely followed by a frontocentral response-locked negativity identified as the Motor Potential (MP; Berchicci et al., 2016; Shibasaki et al., 1980; Vaughan et al., 1968), a reafferent component proposed to reflect the processing of movement-related sensory feedback (Gerbrandt et al., 1973). The current conceptualisation and timing of the MP relative to P3b (and the grand mean RT) implies that MP could reflect the onset of post-response processing.

A novel parietal response-locked positivity, labelled P420, was extracted after the MP in the auditory equiprobable task. P420 was positively associated with better behavioural performance in healthy young adults (i.e., shorter RTs, lower RTV, and fewer omission errors); this general link to performance was considered to support a link between P420 and response evaluation (Fogarty et al., 2020a). Additional research is needed to replicate and clarify the PCA-derived P420, as well as the preceding MP, to determine their functional role in Go/NoGo sequential processing.

Go SW1 peaked after P3b (and P420), approximately 500 ms poststimulus, and was characterised as a large positivity that is maximal at central electrode sites contralateral to the responding hand. The topography of Go SW1 was considered to imply a relationship between SW1 and motor processing; this was confirmed in Study 3, which demonstrated that SW1 amplitudes were enhanced in averaged response-locked ERP data, and negatively associated with RTs (perhaps similar to the P4 in Karlin et al., 1971).

Go SW1 is similar to the Reafferent Potential (RAP), a post-movement positivity that is considered to reflect the evaluation of reafferent sensory input (Bates, 1951; Bötzel et al., 1997; Shibasaki et al., 1980). It is unclear whether the two components are related; however, following the broader ERP literature concerning positive SWs, both Go SW1 and RAP could reflect the evaluation or closure of movement-related processes (Falkenstein et al., 1994; Gajewski et al., 2008; García-Larrea & Cézanne-Bert, 1998); as well as attention (Gevins et al., 1996), or memory processing (e.g., García-Larrea & Cézanne-Bert, 1998; Johnson & Donchin, 1985; Nogueira et al., 2015).

Speculatively, increases in SW1 (and perhaps the preceding P420) could represent greater gain or amplification of movement-related sensory input (e.g., reafferent motor feedback), which could be associated with better cognitive performance in auditory Go/NoGo tasks (Azim & Seki, 2019). Like P2, SW1 increased with Go stimulus probability in Study 1, perhaps reflecting stronger (or enhanced) gating of reafferent somatosensory input with the increased response frequency.

Go SW2 was identified as a parietal (somewhat frontoparietal) scalp negativity that peaked approximately 600–700 ms poststimulus (Fogarty et al., 2019, 2020a). Like Go SW1, it was enhanced in response-locked ERP data, indicating that it reflects mostly response-related neuronal activity; this is consistent with our current hypothesis relating SW2 to late post-response cognitive adjustments, or preparation for ensuing trials, following early research into late negative slow waves in choice/RT tasks (e.g., Desmedt & Debecker, 1979; Rohrbaugh et al., 1978; Ruchkin et al., 1986).

1.2.2. NoGo ERP components

The PCA-derived N2b was a minor frontal negativity peaking approximately 220 ms after NoGo stimuli in the auditory equiprobable Go/NoGo task (e.g., Falkenstein et al., 1999). In Study 1, N2b was shown to significantly increase in amplitude as NoGo stimulus probability decreased (Banquet et al., 1981; Bruin & Wijers, 2002; Hepsomali et al., 2019; Keskin-Ergen et al., 2014; Nieuwenhuis et al., 2003; Wessel, 2018), in line with research linking N2b to cognitive control (for a useful review, see Folstein & Van Petten, 2008). This general and well-established view of N2b was supported by the frontal sources related to that PCA component in Study 2, considering research linking those sources and N2b to control processes such as inhibition (Aron et al., 2003, 2004; Bruin & Wijers, 2002; Falkenstein et al., 1999; Fogarty et al., 2018; Jodo & Kayama, 1992), response conflict monitoring (Botvinick et al., 2001; Ridderikhof et al., 2004; Yeung et al., 2004), or higher-level perceptual processes involved in response selection (Lange et al., 1997).

Healthy young adults exhibited a frontocentral P3a, which peaked about 260 ms after nontargets in the equiprobable (and classic oddball) Go/NoGo tasks, consistent with previous research (e.g., Barry & De Blasio, 2013; O'Connell et al., 2012; Polich, 2007; N. Squires et al., 1975). P3a PCA component amplitudes were larger when NoGo probability was lower, although that finding was not significant (*cf.*, Banquet et al., 1981; Hull & Harsh, 2001; Spencer & Polich, 1999; N. Squires et al., 1975). Study 4 also demonstrated that NoGo P3a amplitudes were not related to behavioural performance (Falkenstein et al., 1999), and their correlation with inhibitory demands was inconsequential (Wessel, 2018). Hence, NoGo P3a cannot reflect response inhibition in this simple paradigm, as it was previously considered (*cf.*, Falkenstein et al., 2002; Fogarty et al., 2018; Kamarajan et al., 2005).

Study 4 also demonstrated that, on average, healthy young adults did not prime Go responses in the auditory equiprobable task, questioning the need for effortful response inhibition in this paradigm (Barry & Rushby, 2006; Wessel, 2018); this implies that the NoGo N2b (or other ERP components) in this task are not likely to reflect response inhibition (Donkers & Van Boxtel, 2004). Thus, it is more likely that the equiprobable NoGo N2b represents decisional processing related to conflict monitoring or response selection, while the subsequent P3a could reflect an internally-directed shift in attention related to initial performance monitoring or evaluation, which is partially consistent with Polich's (2007) neuroinhibition hypothesis and other performance

monitoring views of NoGo P3 (see Huster et al., 2013). As described in Study 4, this view of the NoGo P3a can explain the complex P3a source solution in that study, which linked the component to activity in the premotor and prefrontal cortices, cingulate, precuneus, and postcentral gyrus. Interestingly, these sources included the core executive network noted in Study 2, indicating the continued importance of those cortical areas in later NoGo processing.

Following P3a, NoGo SW1 peaked approximately 400–450 ms after nontargets, and was negative over frontal and midline sites and positive at temporal sites. The frontal SW1 negativity decreased, and temporal positivity increased, when NoGo stimuli were less frequent (Fogarty et al., 2019). NoGo SW2 peaked later, approximately 625 ms poststimulus, and was negative at frontoparietal sites and positive at central sites. The frontoparietal SW2 negativity increased and the central positivity decreased when NoGo probability was lower; this is opposite to the effect shown for NoGo SW1, providing support for the separation of the NoGo SW into two distinct subcomponents.

NoGo SW1 and SW2 were proposed to represent post-response evaluation and preparation similar to that hypothesised for Go SW1 and SW2 (Fogarty et al., 2019, 2020a); however, the electrophysiological processes underpinning the Go and NoGo SW components must differ to some extent, considering their distinct scalp topographies (especially in regard to SW1; *compare* Figures 4 and 6 in Chapter 2). Further research is needed to clarify the role of these components, although we can speculate that the topography of NoGo SW1 reflects executive processing of auditory information in fronto-temporal brain regions. More specifically, the probability effect shown on SW1 could be viewed as a decrease in the demand (or load) on top-down memory or evaluative processes (reduced frontal negativity), and enhanced gating in auditory areas (greater temporal positivity), following an increase in the occurrence of NoGo stimuli; perhaps facilitating post-response evaluation or late auditory processing. In contrast, SW2 may represent preparatory processing (Desmedt & Debecker, 1979; Rohrbaugh et al., 1978; Ruchkin et al., 1986), perhaps relative to the Go/NoGo motor requirements stored in working memory, which could account for the central SW2 positivity. The SW2 probability effect in Study 1 could reflect increased Go trial preparation after lower probability NoGo stimuli, particularly if participants have learned that Go stimuli are more likely.

No distinct Late Positivity (LP) was extracted after NoGo SW1 and SW2 in this thesis. In Barry and De Blasio (2013), the novel LP was identified as a globally positive slow-wave component that peaked at frontocentral sites approximately 700 ms after NoGo stimuli. More recent PCA studies have identified similar components in this auditory task (e.g., Barry & De Blasio, 2015; Barry, De Blasio, & Cave, 2014; Barry et al., 2018, 2019). However, upon closer inspection, those recent "LP" components show topographies that are broadly similar to NoGo SW2. It is possible that SW2 and LP could overlap to some extent (as suggested in Chapter 2), although the two components have been separated recently using PCA (Barry, Fogarty, & De

Blasio, 2019). Further research is needed to clarify these two components; considering their long latencies, they both could be separated more clearly if the epoch that we use in this paradigm is extended beyond 750 ms poststimulus.

1.3. Updating the Go/NoGo Schema

This thesis continued the development of Barry and De Blasio's (2013) Sequential Processing Schema by investigating the temporal PCA-derived ERP components related to auditory Go/NoGo processing in healthy young adults. The major findings in Studies 1–4 clarified the ERP component series associated with previous versions of the Go/NoGo Schema (Barry & De Blasio, 2013; Fogarty et al., 2018), prompting a reconceptualisation of the N1 subcomponents, and thus the sensory (and perceptual) processing theories related to the Schema. Two Go/NoGo SW components were also confirmed using separate PCAs, and the Go P3b, SW1, and SW2 were shown to be primarily response-related, improving the conceptualisation of the ERP component series associated with Go and NoGo response processing in young adults.

Figure 1 displays an updated Sequential Processing Schema that is proposed to integrate the major findings in this doctoral thesis. Relative to the update prior to this thesis (Chapter 1, Figure 3, p. 7), the updates proposed for the young adult Schema include the relabelling of the N1 components, the inclusion of SW1 and SW2 in each processing chain, and the use of italics to represent components that are primarily response-related. P1 and N1b are also underlined red to indicate their enhancement following NoGo stimuli (Fogarty et al., 2020b), and the LP is now faded to illustrate that it has an uncertain place in the Schema, given that it is not always extracted in this task (Borchard et al., 2015; Karamacoska et al., 2018). The response-specific components extracted in Study 3 require further replication and investigation; hence, they are not formally integrated in this update.

New processing labels have been proposed to indicate the functional interpretation of each ERP component and the sequential processing series more appropriately in the Schema. Go/NoGo sensory processing is relabelled as 'perceptual processing' to acknowledge the complex involvement of attention and memory in the P1/N1 stimulus processing stages. Stimulus 'categorisation' is also thought to be finalised earlier with N1c, prior to P2/N2b, considering the early stimulus-specific effects identified in this thesis and Barry et al. (2019). The Go P2, N2c and P3b processing stages are also relabelled as 'target S-R activation', to highlight their involvement in Go-specific stimulus-response (S-R) activation, and to distinguish P3b from post-response processing (the onset of which may be marked by the response-locked MP). Following that, both Go SW1 and SW2 are linked to 'evaluation and adjustment', reflecting their current interpretation as markers of evaluative, memory, and/or preparatory post-response processing; this label is also applied to NoGo SW1, SW2, and LP for similar reasons (moreover, the 'winding-down' associated with LP could reflect an active cognitive adjustment; Barry & De Blasio, 2013). 'NoGo: control and termination' was also replaced by 'NoGo: implicit response processing' to

reflect that young adults may not need response inhibition in the equiprobable task. Nevertheless, N2b and P3a are marked by 'active control', reflecting their links to cognitive control processes like conflict monitoring and attention, which were supported throughout this thesis research.

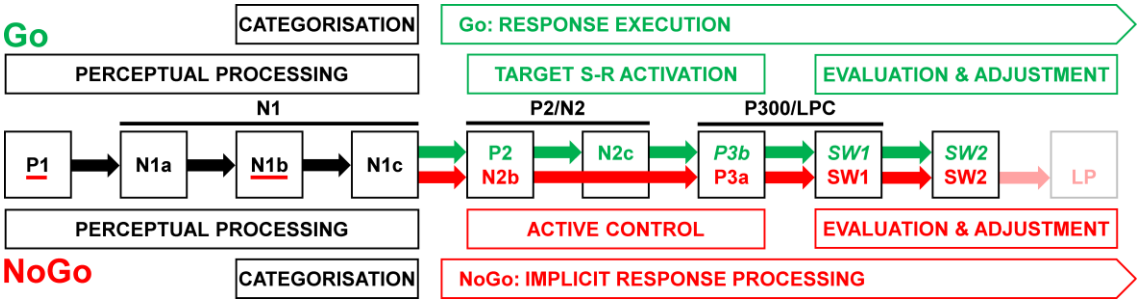


Figure 1. The proposed update to the Go/NoGo Sequential Processing Schema. S-R refers to stimulus-response, and both the P1 and N1b are underlined in red to indicate their enhancements following NoGo stimuli.

Following the update of the Schema in Figure 1, and the general interpretation of each ERP/PCA component in this chapter, auditory equiprobable Go/NoGo processing in healthy young adults is proposed to begin with P1, N1a, N1b, and N1c, reflecting the sequential processing of sensory information (Näätänen & Picton, 1987). Variations in these early components are likely to reflect a selective top-down cortical gain control mechanism acting to facilitate perceptual processing leading to stimulus categorisation and further response processing (Hillyard et al., 1998). Go/NoGo stimulus categorisation is considered to be finalised in the N1b and N1c stages, leading to distinguishable processing chains involving Go 'response execution' and NoGo 'implicit response processing'. Go response execution is marked by P2, N2c, and P3b, reflecting the activation of target stimulus-response processes enabling the Go response (e.g., interference control, conflict monitoring, and the reactivation of S-R links). The subsequent SW1 and SW2 are then considered to reflect Go motor response evaluation and cognitive adjustments potentially involving memory-updating (or retrieval) and preparatory processing. Implicit NoGo response processing is marked by N2b and P3a reflecting active control (e.g., conflict monitoring and attentional control), facilitating the relatively passive maintenance of static behaviour and further NoGo processing, represented by NoGo SW1, SW2, and LP. The late NoGo SW components and LP are also considered to represent evaluation, memory, preparation, and the active winding-down of effortful response processing (Barry & De Blasio, 2013).

The updated Schema presented here is considered to represent a more refined ERP framework of auditory Go/NoGo processing in healthy young adults, relative to previous versions (Barry et al. 2013, 2019; Fogarty et al., 2018). The structural and conceptual developments applied to the Schema in this chapter (and illustrated in Figure 1) are expected to increase the model's utility in future Go/NoGo studies, by providing researchers with a more sophisticated and holistic psychophysiological framework for data-driven ERP research in this paradigm. This is considered to enhance the value of the Schema and the current PCA method as an empirical

tool (or approach) to measure discrete ERP components, and delineate experimental effects on a more complete series of fundamental neurocognitive processes that are linked to auditory equiprobable Go/NoGo processing.

1.4. Further implications, limitations, and future research

As discussed in Chapter 1, the similarity between equiprobable and traditional Go/NoGo or oddball processing is debatable, given that equiprobable tasks are intermediate in Go and NoGo probability relative to those paradigms. However, as shown in Chapter 2, the equiprobable and oddball ERP component series were highly similar, suggesting that the cognitive requirements in those two tasks were almost equivalent. This supports further extrapolation of ERP theory and research between auditory equiprobable and active oddball contexts, consistent with Study 4, which suggested that equiprobable NoGo P3a was more likely an index of attentional processing than response inhibition. Together, these specific outcomes (and others in this thesis) help to clarify the cognitive demands in simple equiprobable tasks, but also imply task differences distinguishing traditional Go/NoGo processing from that in both the equiprobable and oddball variants; that is, primarily, because the traditional 'frequent Go' variants require effortful response inhibition in NoGo trials (e.g., Wessel, 2018).

A limitation of this thesis is the lack of analyses comparing traditional and equiprobable Go/NoGo processing beyond 250 ms poststimulus. The traditional Go/NoGo task could involve a distinct sequential-processing component series, considering the task differences noted above, which may be distinguishable using a focused PCA applied to a later ERP epoch (e.g., 250–750 ms poststimulus). An outstanding question is whether NoGo P3a and the traditional NoGo P3 are distinct ERP components or variations of the same scalp potential (Polich, 2007). Indeed, recent studies have proposed that NoGo P3 in traditional Go/NoGo tasks might reflect performance monitoring (Huster et al., 2013, 2020), and this view could be compatible with the neuroinhibition account of P3a developed in the oddball literature (see Polich, 2007), as discussed regarding the equiprobable P3a in Chapter 5 (pp. 137–139). Exploring this could provide valuable insight into task-specific and -nonspecific P3 functionality and cognitive control. These queries can be addressed in future research; nonetheless, the current thesis outcomes are considered to provide a useful step towards bridging the ERP literature across common Go/NoGo variants.

Processing in the Go/NoGo Schema is represented by orthogonal ERP components that reflect stages of cognitive task processing. Despite each PCA component being statistically independent, sequential processing in the Schema may be considered to occur in a graded (or continuous) fashion, rather than strictly stage-based (*cf.* Sternberg, 1969). Indeed, the core frontal sources identified across multiple components in Chapter 3 could reflect continuity across component-oriented processing stages at the level of the cortex. Graded processing can also be reflected in the temporal overlap of the PCA component waveforms, evident in their factor loadings. However, given that orthogonal solutions can inflate cross-loadings (Sass & Schmitt,

2010; Scharf & Nestler, 2018a; Schmitt & Sass, 2011), researchers should be careful interpreting the temporal overlap of PCA factors, and consider comparing factors quantified using various rotations if component onset/offset latencies are of particular interest.

The ERP source outcomes in this thesis suggest that each component can represent a complex interaction between ongoing executive processes and discrete cognitive functions, consistent with a parallel distributed processing framework of information processing (Cohen et al., 1990). This view emphasises the relationship between tonic control and task-related information (e.g., goals, strategies, and rules), and the phasic neuronal responses in each component (e.g., motor activation), although the phasic aspect is often considered to account for ERP components entirely. Further research to decompose and study the temporal characteristics of the cortical networks related to the ERP component series in this thesis would be useful to understand the complex neurocognitive processing underpinning scalp potentials and clarify sequential Go/NoGo processing at a cortical level. However, it is important to note that eLORETA, the algorithm used for source localisation in this research, is a distributed model that uses a Laplacian 'smoothing' constraint to find a solution to the inverse problem (Pascual-Marqui, 2007, 2009; Pascual-Marqui et al., 2011). This approach has been validated extensively in relation to MRI research and is thought to be highly accurate (Pascual-Marqui, 1999, 2002; Pascual-Marqui et al., 2002), but it has low spatial resolution due to the smoothing constraint (Michel et al., 2004), which may have inflated the number of active ERP sources identified in Chapters 3 and 5. Hence, the complexity of the current source outcomes should be considered carefully as a guide for further research exploring component networks.

A major strength of the ERP research underpinning the Schema is the consistent and systematic application of the PCA method described in Chapter 1 and Barry et al. (2016). However, while the current PCA approach is considered useful and effective, it may not be the most optimal. The use of Varimax to maintain the orthogonality of PCA components has distinct advantages for ERP component analysis; specifically, Varimax solutions have little redundancy in the rotated factor solution, which effectively simplifies the interpretation and analysis of extracted components (Barry et al., 2016; Donchin & Heffley, 1978; Kayser & Tenke, 2003; Van Boxtel, 1998). However, Varimax rotation might not be the best method to quantify the sequential or continuous processing in ERP data. Promax, or other oblique methods of factor rotation, may provide a better or more realistic factor solution by relaxing the orthogonality restraints on the PCA (see Dien, 1998, 2010; Dien & Frishkoff, 2005). Previous studies also indicate that oblique factor rotation achieves a closer approximation of Thurston's (1947) simple structure than orthogonal methods (Dien et al., 2005, 2007; Scharf & Nestler, 2018b). Thus, using Varimax in this thesis could be considered a limitation that needs to be addressed in future research, which should investigate the potential of other ERP methods to optimise the Schema and our ability to delineate sequential task processing; this may include alternate PCA parameters (e.g., Promax

rotation), or other signal processing techniques including Residue Iteration Decomposition (see Ouyang et al., 2011, 2015), Shifted Factor Analysis (e.g., Harshman et al., 2003; Hong & Harshman, 2003a, b; Knuth, 2006; Kohl et al., 2010; Mørup et al., 2007, 2008), or single-trial methods similar to the approach developed in Study 4.

Preparation in the auditory equiprobable Go/NoGo task is also still unclear, although this thesis showed that, on average, healthy young adults do not prime the Go response (as indexed by LRP). However, the current hypotheses linking P1, N1, and P2 to sensory gating and interference control, and SW2 to readiness or cognitive adjustments, implies the role of selective and preparatory processing. Further research should aim to investigate control processing more directly in relation to the sequential processing in this task, perhaps by exploring the application of Braver's (2012) dual mechanisms of control (i.e., proactive vs. reactive processing) in relation to the Schema; this could assist in elucidating useful ERP markers of cognitive control and potentially explain developmental differences previously identified in Go/NoGo task processing (Barry, De Blasio, & Borchard, 2014; Barry, De Blasio, & Cave, 2016; Johnstone et al., 2005; Jonkman, 2006; Jonkman et al., 2003). For example, children find equiprobable tasks more difficult and exhibit larger N2b components in NoGo trials compared to adults (Barry, De Blasio, & Borchard, 2014), perhaps reflecting a more reactive response, demanding effortful control for NoGo trials (Barry & De Blasio, 2015). In that manner, exploring the dual mechanisms of control in the Schema could provide useful insight into the development of information and control processing across the lifespan.

The relationship between the current ERP findings and those in other task modalities or designs (e.g., visual or cued Go/NoGo tasks) was not considered in detail throughout this research as there were no data to support alternate task comparisons. This may be viewed as a limitation to the generalisability of this research, however, the focused scope of this thesis is also a strength in that it provides a systematic and comprehensive characterisation of auditory Go/NoGo processing; other ERP task comparisons are better explored in research designed specifically for that purpose, and some useful research has already been conducted to that end (e.g., Falkenstein et al., 1995; Gajewski & Falkenstein, 2013; Key & Yoder, 2013; Simson et al., 1977; Spencer et al., 2001).

In relation to the Sequential Processing Schema, it is important to note that many researchers have their own schemas regarding ERP components and the functions that they represent in a given task; some have been published previously, primarily to form hypotheses regarding latent subcomponents, such as those underlying the N1 or P3 components (e.g., Falkenstein et al., 1995; Näätänen et al., 2011; Näätänen & Picton, 1987; Polich, 2007). Relative to those component-specific models, the work formalising the Sequential Processing Schema reflects an effort to investigate ERP components and develop a more holistic (i.e., complete) data-

driven conceptualisation and quantification of Go/NoGo processing, to clarify and measure the neurocognitive processes in that common paradigm.

Using PCA to quantify the full Go/NoGo processing series improves the measurement of ERP components as overlapping factors in the series are more easily separated with more data (i.e., timepoints and cases). Generally, the interpretation of components is also easier when it is possible to compare the timing and topography of a component relative to others in the factor series. From that perspective, a holistic PCA approach can increase the utility and interpretability of ERP outcomes as researchers are able to consider specific study findings relative to other factors and the broader 'component-oriented' task processing requirements, even if only one factor is of interest to the study authors. Observing the processing series in this manner is efficient for modelling a range of cognitive task demands and exploring the impact of experimental effects or neurocognitive deficits on various mental functions. In that sense, the Schema is considered a research tool that can be utilised to framework and interpret ERP outcomes, however, further study is needed to test the advantages and implications of other data-driven ERP methods for modelling cognitive task processing series (e.g., Promax rotation or shifted factor analyses). Additional research is also needed to explore the utility of the Schema in clinical investigations and compare the ERP processing series in these tasks with other cognitive paradigms, to work towards a consensus regarding the ERP components and measurable processing demands in common cognitive tasks.

1.5. Conclusion

This doctoral thesis clarified the ERP markers of auditory Go/NoGo processing in healthy young adults by exploring temporal PCA-derived ERP component functionality and continuing the development of Barry and De Blasio's (2013) Sequential Processing Schema. The four studies in this thesis provided valuable insight that can support theoretical advances in areas associated with a range of Go/NoGo ERP components and executive functions, contributing to the development of common ERP components as potential indices of important mental functions. Nesting those complex ERP findings within the broader Go/NoGo processing series also provided useful insight into basic information processing in healthy young adults, and these outcomes were considered to help clarify the cognitive requirements in auditory equiprobable Go/NoGo tasks, which can guide future research utilising that common paradigm. The study outcomes reviewed here also resulted in a major update to the young adult Sequential Processing Schema, improving its utility as a data-driven research tool for studying a range of psychophysiological processes. Applying the updated Schema in future research is encouraged to promote a greater synthesis of Go/NoGo ERP theory and research in psychophysiology, and to delineate cognitive processing associated with different task demands or psychopathologies.

References

Aron, A. R., Fletcher, P. C., Bullmore, E. T., Sahakian, B. J., & Robbins, T. W. (2003). Stop-signal inhibition disrupted by damage to the right inferior frontal gyrus in humans. *Nature Neuroscience, 6*(2), 115–116. https://doi.org/10.1038/nn1003

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition in the right inferior frontal cortex. *Trends in Cognitive Neurociences, 8*(4), 170–177. https://doi.org/10.1016/j.tics.2004.02.010

Azim, E., & Seki, K. (2019). Gain control in the sensorimotor system. *Current Opinion in Physiology, 8*, 177–187. https://doi.org/10.1016/j.cophys.2019.03.005

Banquet, J. P., Renault, B., & Lesèvre, N. (1981). Effect of task and stimulus probability on evoked potentials. *Biological Psychology, 13*, 203–214. https://doi.org/10.1016/0301-0511(81)90036-3

Barry, R. J., & De Blasio, F. M. (2013). Sequential processing in the equiprobable auditory Go/NoGo task: A temporal PCA study. *International Journal of Psychophysiology, 89*(1), 123–127. https://doi.org/10.1016/j.ijpsycho.2013.06.012

Barry, R. J., De Blasio, F. M., & Borchard, J. P. (2014a). Sequential processing in the equiprobable auditory Go/NoGo task: Children vs. adults. *Clinical Neurophysiology, 125*(10), 1995–2006. http://doi.org/10.1016/j.clinph.2014.02.018

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2014b). Caffeine effects on erp components and performance in an equiprobable auditory go/nogo task. *Journal of Caffeine Research, 4*(3), 83–92. https://doi.org/10.1089/jcr.2014.0011

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2016a). Sequential processing in young and older adults in the equiprobable auditory Go/NoGo task. *Clinical Neurophysiology, 127*(5), 2273–2285. https://doi.org/10.1016/j.clinph.2016.02.010

Barry, R. J., De Blasio, F. M., & Fogarty, J. S. (2018). A processing schema for children in the auditory equiprobable Go/NoGo task: ERP components and behaviour. *International Journal of Psychophysiology, 123*, 74–79. https://doi.org/10.1016/j.ijpsycho.2017.10.014

Barry, R. J., De Blasio, F. M., Fogarty, J. S., & Karamacoska, D. (2016b). ERP Go/NoGo condition effects are better detected with separate PCAs. *International Journal of Psychophysiology, 106*, 50–64. https://doi.org/10.1016/j.ijpsycho.2016.06.003

Barry, R. J., Fogarty, J. S., & De Blasio, F. M. (2020). Caffeine as a tool to explore active cognitive processing stages in two-choice tasks. *Journal of Caffeine and Adenosine Research, 00*(00). https://doi.org/10.1089/caff.2019.0021

Barry, R. J., & Rushby, J. A. (2006). An orienting reflex perspective on anteriorisation of the P3 of the event-related potential. *Experimental Brain Research, 173*(3), 539–545. https://doi.org/10.1007/s00221-006-0590-8

Bates, J. A. V. (1951). Electrical activity of the cortex accompanying movement. *The Journal of Physiology*, *113*(2–3), 240–257. https://doi.org/10.1113/jphysiol.1951.sp004569

Bender, S., Oelkers-Ax, R., Resch, F., & Weisbrod, M. (2006). Frontal lobe involvement in the processing of meaningful auditory stimuli develops during childhood and adolescence. *NeuroImage*, *33*(2), 759–773. https://doi.org/10.1016/j.neuroimage.2006.07.003

Benedict, R. H. B., Lockwood, A. H., Shucard, J. L., Shucard, D. W., Wack, D., & Murphy, B. W. (1998). Functional neuroimaging of attention in the auditory modality. *NeuroReport, 9*(1), 121–126. https://doi.org/10.1097/00001756-199801050-00024

Berchicci, M., Spinelli, D., & Di Russo, F. (2016). New insights into old waves. Matching stimulus- and response-locked ERPs on the same time-window. *Biological Psychology, 117,* 202–215. https://doi.org/10.1016/j.biopsycho.2016.04.007

Borchard, J. P., Barry, R. J., & De Blasio, F. M. (2015). Sequential processing in an auditory equiprobable Go/NoGo task with variable interstimulus interval. *International Journal of Psychophysiology, 97*(2), 145–152. https://doi.org/10.1016/j.ijpsycho.2015.05.010

Bosnyak, D. J., Eaton, R. A., & Roberts, L. E. (2004). Distributed auditory cortical representations are modified when non-musicians are trained at pitch discrimination with 40 Hz amplitude modulated tones. *Cerebral Cortex, 14,* 1088–1099. https://doi.org/10.1093/cercor/bhh068

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*(3), 624–652. https://doi.org/10.1037/0033-295X.108.3.624

Bötzel, K., Ecker, C., & Schulze, S. (1997). Topography and dipole analysis of reafferent electrical brain activity following the Bereitschaftspotential. *Experimental Brain Research, 114,* 352–361. https://doi.org/10.1007/PL00005643

Boulinguez, P., Ballanger, B., Granjon, L., & Benraiss, A. (2009). The paradoxical effect of warning on reaction time: demonstrating proactive response inhibition with event-related potentials. *Clinical Neurophysiology, 120*(4), 730–737. https://doi.org/10.1016/j.clinph.2009.02.167

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106–113. https://doi.org/10.1016/j.tics.2011.12.010

Braver, T. S., Barch, D. M., Gray, J. R., Molfese, D. L., & Snyder, A. (2001). Anterior cingulate cortex and response conflict: Effects of frequency, inhibition and errors. *Cerebral Cortex, 11*(9), 825-836. https://doi.org/10.1093/cercor/11.9.825

Brigham, J., Herning, R. I., & Moss, H. B. (1995). Event-related potentials and alpha synchronization in preadolescent boys at risk for psychoactive substance use. *Biological Psychiatry, 37*(12), 834–846. https://doi.org/10.1016/0006-3223(94)00218-R

Brydges, C. R., & Barceló, F. (2018). Functional dissociation of latency-variable, stimulus- and

response-locked target P3 sub-components in task-switching. *Frontiers in Human Neuroscience*, *12*, 1–14. https://doi.org/10.3389/fnhum.2018.00060

Bruin, K. J., & Wijers, A. A. (2002). Inhibition, response mode, and stimulus probability: A comparative event-related potential study. *Clinical Neurophysiology*, *113*(7), 1172–1182. https://doi.org/10.1016/S1388-2457(02)00141-4

Budd, T. W., Barry, R. J., Gordon, E., Rennie, C., & Michie, P. T. (1998). Decrement of the N1 auditory event-related potential with stimulus repetition: habituation vs. refractoriness. *International Journal of Psychophysiology*, *31*(1), 51–68. https://doi.org/10.1016/s0167-8760(98)00040-3

Burkhard, A., Elmer, S., & Jäncke, L. (2019). Early tone categorization in absolute pitch musicians is subserved by the right-sided perisylvian brain. *Scientific reports*, *9*(1), 1–14. https://doi.org/10.1038/s41598-018-38273-0

Cabeza, R., & Nyberg, L. (1997). Imaging cognition: A empirical review of PET studies with normal subjects. *Journal of Cognitive Neuroscience*, *9*(1), 1–26. https://doi.org/10.1162/jocn.1997.9.1.1

Catalan, M. J., Honda, M., Weeks, R. A., Cohen, L. G., & Hallet, M. (1998). The functional neuroanatomy of simple and complex sequential finger movements: A PET study. *Brain*, *121*(2), 253–264. https://doi.org/10.1093/brain/121.2.253

Coch, D., Skendzel, W., & Neville, H. J. (2005). Auditory and visual refractory period effects in children and adults: An ERP study. *Clinical Neurophysiology*, *116*(9), 2184–2203. https://doi.org/10.1016/j.clinph.2005.06.005

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review*, *97*(3), 332–361. https://doi.org/10.1037/0033-295x.97.3.332

Conroy, M. a., & Polich, J. (2007). Normative variation of P3a and P3b from a large sample: Gender, topography, and response time. *Journal of Psychophysiology*, *21*(1), 22–32. https://doi.org/10.1027/0269-8803.21.1.22

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-drive attention in the brain. *Nature Reviews Neuroscience*, *3*(3), 201-215. https://doi.org/10.1038/nrn755

Criaud, M., & Boulinguez, P. (2013). Have we been asking the right questions when assessing response inhibition in go/no-go tasks with fMRI? A meta-analysis and critical review. *Neuroscience and Biobehavioral Reviews*, *37*(1), 11–23. https://doi.org/10.1016/j.neubiorev.2012.11.003

Crowley, K. E., & Colrain, I. M. (2004). A review of the evidence for P2 being an independent component process: Age, sleep and modality. *Clinical Neurophysiology*, *115*(4), 732–744. https://doi.org/10.1016/j.clinph.2003.11.021

Dalbokova, D., Gille, H. G., & Ullsperger, P. (1990). Amplitude variations in P300 component

due to unpredictable stepwise change of stimulus probability. *International Journal of Psychophysiology*, *10*(1), 33–38. https://doi.org/10.1016/0167-8760(90)90042-C

Desmedt, J. E., & Debecker, J. (1979). Slow potential shifts and decision P350 interactions in tasks with random sequences of near-threshold clicks and finger stimuli delivered at regular intervals. *Electroencephalography and Clinical Neurophysiology*, *47*, 671–679. https://doi.org/10.1016/0013-4694(79)90294-3

Dien, J. (1998). Addressing misallocation of variance in principal components analysis of event-related potentials. *Brain Topography*, *11*(1), 43–55. https://doi.org/10.1023/A

Dien, J. (2010). Evaluating two-step PCA of ERP data with Geomin, Infomax, Oblimin, Promax, and Varimax rotations. *Psychophysiology*, *47(1)*, 170–183. https://doi.org/10.1111/j.1469-8986.2009.00885.x

Dien, J., Beal, D. J., & Berg, P. (2005). Optimizing principal components analysis of event-related potentials: Matrix type, factor loading weighting, extraction, and rotations. *Clinical Neurophysiology, 116(8)*, 1808–1825. https://doi.org/10.1016/j.clinph.2004.11.025

Dien, J., & Frishkoff, G. A. (2005). Introduction to principal components analysis of event-related potentials. In T. Handy (Ed.), *Event-related potentials: A methods handbook* (pp. 189–208). Cambridge, MA: MIT Press.

Dien, J., Khoe, W., & Mangun, G. R. (2007). Evaluation of PCA and ICA of simulated ERPs: Promax vs. infomax rotations. *Human Brain Mapping*, *28(8)*, 742–763. https://doi.org/10.1002/hbm.20304

Di Russo, F., Berchicci, M., Bozzacchi, C., Perri, R. L., Pitzalis, S., & Spinelli, D. (2017). Beyond the "Bereitschaftspotential": Action preparation behind cognitive functions. *Neuroscience and Biobehavioral Reviews, 78*, 57–81. https://doi.org/10.1016/j.neubiorev.2017.04.019

Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioural and Brain Sciences. 11*(3), 357–374. https://doi.org/10.1017/S0140525X00058027

Donchin, E., & Heffley, E. F. (1978). Multivariate analysis of event-related potential data: A tutorial review. In D. A. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (pp. 555–572). Washington, DC: U.S. Government Printing Office.

Donchin, E., Spencer, K. M., & Dien, J. (1997). The varieties of deviant experience: ERP manifestations of deviance processors. In G. J. M. Van Boxtel & K. B. E. Bocker (Eds.), *Brain and Behavior: Past, Present, and Future* (pp. 67–91). Tilburg University Press.

Donkers, F. C. L., & Van Boxtel, G. J. M. (2004). The N2 in go/no-go tasks reflects conflict

monitoring not response inhibition. *Brain and Cognition*, *56*(2), 165-176. http://doi.org/10.1016/j.bandc.2004.04.005

Duncan-Johnson, C. C., & Donchin, E. (1977). On quantifying surprise: The variation of event-related potentials with subjective probability. *Psychophysiology*, *14*(5), 456–467. https://doi.org/10.1111/j.1469-8986.1977.tb01312.x

Duncan-Johnson, C. C., & Donchin, E. (1982). The P300 component of the event-related brain potential as an index of information processing. *Biological Psychology*, *14*(1–2), 1–52. https://doi.org/10.1016/0301-0511(82)90016-3

Elvira, B., Tervaniemi, M., & Picton, T. W. (2003). Effects of brief discrimination-training on the auditory N1 wave. *NeuroReport*, *14*(18), 2489–2492. https://doi.org/10.1097/01.wnr.0000098748.87269.a1

Falkenstein, M., Hohnsbein, J., & Hoormann, J. (1994). Effects of choice complexity on different subcomponents of the late positive complex of the event-related potential. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials*, *92*, 148–160. https://doi.org/10.1016/0168-5597(94)90055-8

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroencephalography and Clinical Neurophysiology*, *78*(6), 447–455. https://doi.org/10.1016/0013-4694(91)90062-9

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica*, *101*(2–3), 267–291. https://doi.org/10.1016/S0001-6918(99)00008-6

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (2002). Inhibition-related ERP components: Variation with modality, age, and time-on-task. *Journal of Psychophysiology*, *16*(3), 167–175. https://doi.org/10.1027//0269-8803.16.3.167

Falkenstein, M., Koshlykova, N. a, Kiroj, V. N., Hoormann, J., & Hohnsbein, J. (1995). Late ERP components in visual and auditory Go/Nogo tasks. *Electroencephalography and Clinical Neurophysiology*, *96*(94), 36–43. https://doi.org/10.1016/0013-4694(94)00182-K

Filipović, S. R., Jahanshahi, M., & Rothwell, J. C. (2000). Cortical potentials related to the nogo decision. *Experimental Brain Research*, *132*(3), 411–415.

Fitzgerald, P. G., & Picton, T. W. (1981). Temporal and sequential probability in evoked potential studies. *Canadian Journal of Psychology*, *35*(2), 188–200. https://doi.org/10.1037/h0081154

Fogarty, J. S., Barry, R. J., De Blasio, F. M., & Steiner, G. Z. (2018). ERP components and behavior in the auditory equiprobable go/no-go task: Inhibition in young adults. *Psychophysiology*, *55*(7), Article e13065. https://doi.org/10.1111/psyp.13065

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2019). Sequential processing in the classic oddball task: ERP components, probability, and behavior. *Psychophysiology*, *56*(3), Article e13300. https://doi.org/10.1111/psyp.13300

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2020a). Auditory stimulus- and response-locked ERP components and behavior. *Psychophysiology*, *57*(5), Article e13538. https://doi.org/10.1111/psyp.13538

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2020b). The first 250 ms of auditory processing: No evidence of early processing negativity in the Go/NoGo task. *Scientific Reports, 10*(1), Article 4041. https://doi.org/10.1038/s41598-020-61060-9

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology, 45*(1), 152–170. https://doi.org/10.1111/j.1469-8986.2007.00602.x

Friedman, D. (1984). P300 and slow wave: the effects of reaction time quartile. *Biological Psychology, 18*(1), 49–71. https://doi.org/10.1016/0301-0511(84)90028-0

Gajewski, P. D., & Falkenstein, M. (2013). Effects of task complexity on ERP components in Go/Nogo tasks. *International Journal of Psychophysiology*, *87*(3), 273–278. https://doi.org/10.1016/j.ijpsycho.2012.08.007

Gajewski, P. D., Stoerig, P., & Falkenstein, M. (2008). ERP-correlates of response selection in a response conflict paradigm. *Brain Research*, *1189*(1), 127–134. https://doi.org/10.1016/j.brainres.2007.10.076

García-Larrea, L., & Cézanne-Bert, G. (1998). P3, positive slow wave and working memory load: a study on the functional correlates of slow wave activity. *Electroencephalography and Clinical Neurophysiology*, *108*, 260–273. https://doi.org/10.1016/s0168-5597(97)00085-3

García-Larrea, L., Lukaszewicz, A. C., & Mauguire, F. (1992). Revisiting the oddball paradigm. Non-target vs neutral stimuli and the evaluation of ERP attentional effects. *Neuropsychologia*, *30*(8), 723–741. https://doi.org/10.1016/0028-3932(92)90042-K

Gerbrandt, L. K., Goff, W. R., & Smith, D. B. (1973). Distribution of the human average movement potential. *Electroencephalography and Clinical Neurophysiology*, *34*, 461–474. https://doi.org/10.1016/0013-4694(73)90064-3

Gevins, A., Smith, M. E., Harrison Leong, J. L., Bennett, J., Martin, N., McEvoy, L., Du, R., & Whitfield, S. (1996). High resolution evoked potential imaging of the cortical dynamics of human working memory. *Electroencephalography and Clinical Neurophysiology, 98,* 327–348. https://doi.org/10.1016/0013-4694(96)00288-X

Gonzalez-Rosa, J. J., Inuggi, A., Blasi, V., Cursi, M., Annovazzi, P., Comi, G., Falini, A., & Leocani, L. (2013). Response competition and response inhibition during different choice-discrimination tasks: Evidence from ERP measured inside MRI scanner.

International Journal of Psychophysiology, 89(1), 37–47. https://doi.org/10.1016/j.ijpsycho.2013.04.021

Goodin, D. S., Aminoff, M. J., & Mantle, M. M. (1986). Subclasses of event-related potentials: response-locked and stimulus-locked components. *Annals of Neurology, 20*, 603–609. https://doi.org/10.1002/ana.410200508

Harshman, R. A., Hong, S., & Lundy, M. E. (2003). Shifted factor analysis - Part I: Models and properties. *Journal of Chemometrics, 17(7)*, 363–378. https://doi.org/10.1002/cem.808

Hepsomali, P., Hadwin, J. A., Liversedge, S. P., Degno, F., & Garner, M. (2019). The impact of cognitive load on processing efficiency and performance effectiveness in anxiety: evidence from event-related potentials and pupillary responses. *Experimental Brain Research, 237*(4), 897–909. https://doi.org/10.1007/s00221-018-05466-y

Hermanutz, M., Cohen, R., & Sommer, W. (1981). The effects of serial order in long sequences of auditory stimuli on event-related potentials. *Psychophysiology, 18*(4), 415–423. https://doi.org/10.1111/j.1469-8986.1981.tb02473.x

Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science, 182*(4108), 177–180. https://doi.org/10.1126/science.182.4108.177

Hillyard, S. A., & Kutas, M. (1983). Electrophysiology of cognitive processing. *Annual Reviews of Psychology, 34*, 33–61. https://doi.org/10.1146/annurev.ps.34.020183.000341

Hillyard, S. A., & Mangun, G. R. (1987) Sensory gating as a physiological mechanism for visual selective attention. In R. Johnson, R. Parasuraman, & J. W. Rohrbaugh (Eds.), *Current trends in event-related potential research* (pp. 61–67). Amsterdam: Elsevier

Hillyard, S. A., Vogel, E. K., & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism for selective attention: Electrophysiology and neuroimaging evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences, 353*(1373), 1257-1270. https://doi.org/10.1098/rstb.1998.0281

Hong, S., & Harshman, R. A. (2003a). Shifted factor analysis - Part II: Algorithms. *Journal of Chemometrics, 17(7)*, 379–388. https://doi.org/10.1002/cem.809

Hong, S., & Harshman, R. A. (2003b). Shifted factor analysis - Part III: N-way generalization and application. *Journal of Chemometrics, 17(7)*, 389–399. https://doi.org/10.1002/cem.810

Hull, J., & Harsh, J. (2001). P300 and sleep-related positive waveforms (P220, P450, and P900) have different determinants. *European Sleep Research Society, 10*, 9–17. https://doi.org/10.1046/j.1365-2869.2001.00238.x

Huster, R. J., Enriquez-Geppert, S., Lavallee, C. F., Falkenstein, M., & Herrmann, C. S. (2013). Electroencephalography of response inhibition tasks: functional networks and cognitive contributions. *International Journal of Psychophysiology, 87*(3), 217–233.

https://doi.org/10.1016/j.ijpsycho.2012.08.001

Huster, R. J., Messel, M. S., Thunberg, C., & Raud, L. (2020). The P300 as marker of inhibitory control - Fact or fiction?. *Cortex, 132*, 334–348. https://doi.org/10.1016/j.cortex.2020.05.021

Jerger, K., Biggins, C., & Fein, G. (1992). P50 suppression is not affected by attentional manipulations. *Biological Psychiatry, 31*(4), 365–377. https://doi.org/10.1016/0006-3223(92)90230-w

Jodo, E., & Kayama, Y. (1992). Relation of a negative ERP component to response inhibition in a Go/No-go task. *Electroencephalography and Clinical Neurophysiology, 82*, 477–482. https://doi.org/10.1016/0013-4694(92)90054-L

Johannes, S., Münte, T. F., Heinze, H. J., Mangun, G. R. (1995). Luminance and spatial attention effects on early visual processing. *Cognitive Brain Research, 2,* 189–205. https://doi.org/10.1016/0926-6410(95)90008-x

Johnson, R, Jr., & Donchin, E. (1985). Second thoughts: Multiple P300s elicited by a single stimulus. *Psychophysiology, 22*(2), 182–194. https://doi.org/10.1111/j.1469-8986.1985.tb01584.x

Johnstone, S. J., Pleffer, C. B., Barry, R. J., Clarke, A. R., & Smith, J. L. (2005). Development of inhibitory processing during the go/nogo task. *Journal of Psychophysiology, 19(1),* 11–23. https://doi.org/10.1027/0269-8803.19.1.11

Jonkman, L. M. (2006). The development of preparation, conflict monitoring and inhibition from early childhood to young adulthood; a Go/Nogo ERP study. *Brain research, 1097(1),* 181–193. https://doi.org/10.1016/j.brainres.2006.04.064

Jonkman, L. M., Lansbergen, M., & Stauder, J. E. A. (2003). Developmental differences in behavioral and event-related brain responses associated with response preparation and inhibition in a go/nogo task. *Psychophysiology, 40(5),* 752–761. https://doi.org/10.1111/1469-8986.00075

Joos, K., Gilles, A., Van de Heyning, P., De Ridder, D., & Vanneste, S. (2014). From sensation to percept: The neural signature of auditory event-related potentials. *Neuroscience and Biobehavioral Reviews, 42*, 148–156. https://doi.org/10.1016/j.neubiorev.2014.02.009

Kamarajan, C., Porjesz, B., Jones, K. A., Choi, K., Chorlian, D. B., Padmanabhapillai, A., Rangaswamy, M., Stimus, A. T., & Begleiter, H. (2005). Alcoholism is a disinhibitory disorder: Neurophysiological evidence from a Go/No-Go task. *Biological Psychology, 69*(3), 353–373. https://doi.org/10.1016/j.biopsycho.2004.08.004

Karamacoska, D., Barry, R. J., Steiner, G. Z., Coleman, E. P., & Wilson, E. J. (2018). Intrinsic EEG and task-related changes in EEG affect Go/NoGo task performance. *International Journal of Psychophysiology, 125*, 17–28. https://doi.org/10.1016/j.ijpsycho.2018.01.015

Kayser, J., & Tenke, C. E. (2003). Optimizing PCA methodology for ERP component identification and measurement: Theoretical rationale and empirical evaluation. *Clinical Neurophysiology, 114*(12), 2307–2325. https://doi.org/10.1016/S1388-2457(03)00241-4

Keskin-Ergen, Y., Tükel, R., Aslantaş-Ertekin, B., Ertekin, E., Oflaz, S., & Devrim-Üçok, M. (2014). N2 and P3 potentials in early-onset and late-onset patients with obsessive-compulsive disorder. *Depression and Anxiety, 31*(12), 997–1006. https://doi.org/10.1002/da.22212

Knight, R. T., Grabowecky, M. F., & Scabini, D. (1995). Role of human prefrontal cortex in attention control. In H. H. Jasper, S. Riggio, & P. S. Goldman-Rakic (Eds.), *Advances in neurology, Vol. 66. Epilepsy and the functional anatomy of the frontal lobe* (pp. 21–36). Raven Press.

Knight, R. T., Scabini, D., & Woods, D. L. (1989). Prefrontal cortex gating of auditory transmission in humans. *Brain Research, 504*(2), 338–342. https://doi.org/10.1016/0006-8993(89)91381-4

Knuth, K. H. (2006). Differentially variable component analysis: Identifying multiple evoked components using trial-to-trial variability. *Journal of Neurophysiology, 95(5)*, 3257–3276. https://doi.org/10.1152/jn.00663.2005

Ko, D., Kwon, S., Lee, G. T., Im, C. H., Kim, K. H., & Jung, K. Y. (2012). Theta oscillation related to the auditory discrimination process in mismatch negativity: Oddball versus control paradigm. *Journal of Clinical Neurology (Korea), 8*(1), 35–42. https://doi.org/10.3988/jcn.2012.8.1.35

Kohl, F., Wübbeler, G., Kolossa, D., Bar, M., Orglmeister, R., & Elster, C. (2010). Shifted factor analysis for the separation of evoked dependent MEG signals. *Physics in Medicine and Biology, 55*(15), 4219–4230. https://doi.org/10.1088/0031-9155/55/15/002

Kok, A., Ramautar, J. R., De Ruiter, M. B., Band, G. P. H., & Ridderinkhof, K. R. (2004). ERP components associated with successful and unsuccessful stopping in a stop-signal paradigm. *Psychophysiology, 41*(1), 9–20. https://doi.org/10.1046/j.1469-8986.2003.00127.x

Kornhuber, H. H., & Deecke, L. (2016). Brain potential changes in voluntary and passive movements in humans: Readiness potential and reafferent potentials. *Pflugers Archiv European Journal of Physiology, 468*, 1115–1124. https://doi.org/10.1007/s00424-016-1852-3

Kudela, P., Boatman-Reich, D., Beeman, D, & Anderson, W. S. (2018). Modeling neural adaptation in auditory cortex. *Frontiers in Neural Circuits, 12*, Article 72. https://doi.org/10.3389/fncir.2018.00072

Lange, D. H., Pratt, H., & Inbar, G. F. (1997). Modeling and estimation of single evoked brain

potential components. *IEEE Transactions on Biomedical Engineering, 44*(9), 791–799. https://doi.org/10.1109/10.623048

Lijffijt, M., Lane, S. D., Meier, S. L., Boutros, N. N., Burroughs, S., Steinberg, J. L., Moeller, F. G., & Swann, A. C. (2009). P50, N100, and P200 sensory gating: Relationships with behavioral inhibition, attention, and working memory. *Psychophysiology, 46*(5), 1059–1068. https://doi.org/10.1111/j.1469-8986.2009.00845.x

Marzecová, A., Widmann, A., SanMiguel, I., Kotz, S. A., & Schröger, E. (2017). Interrelation of attention and prediction in visual processing: Effects of task-relevance and stimulus probability. *Biological Psychology, 125*, 76–90. https://doi.org/10.1016/j.biopsycho.2017.02.009

Mayer, A. R., Harrington, D., Adair, J. C., & Lee, R. (2006). The neural networks underlying endogenous auditory covert orienting and reorienting. *NeuroImage, 30*(3), 938–949. https://doi.org/10.1016/j.neuroimage.2005.10.050

McCallum, W. C., & Curry, S. H. (1980). The form and distribution of auditory event related potentials and CNVs when stimuli and responses are lateralized. In H. H. Kornhuber & L. Deecke (Eds.), *Motivation, motor and sensory processes of the brain: Electrical potentials, behaviour and clinical use* (pp. 767–775). Elsevier.

McCarley, R. W., Faux, S. F., Shenton, M. E., Nestor, P. G., & Adams, J. (1991). Event-related potentials in schizophrenia: their biological and clinical correlates and a new model of schizophrenic pathophysiology. *Schizophrenia Research, 4*(2), 209–231. https://doi.org/10.1016/0920-9964(91)90034-o

Michel, C. M., Murray, M. M., Lantz, G., Gonzalez, S., Spinelli, L., & de Peralta, R. G. (2004). EEG source imaging. *Clinical Neurophysiology, 115*(10), 2195–2222. https://doi.org/10.1016/j.clinph.2004.06.001

Mørup, M., Hansen, L. K., Arnfred, S. M., Lim, L. H., & Madsen, K. H. (2008). Shift-invariant multilinear decomposition of neuroimaging data. *NeuroImage, 42(4)*, 1439–1450. https://doi.org/10.1016/j.neuroimage.2008.05.062

Mørup, M., Madsen, K. H., & Hansen, L. K. (2007). Shifted independent component analysis. In M. E. Davies, C. J. James, S. A. Abdallah, & M. D. Plumbley (Eds.), *Independent component analysis and signal separation. ICA 2007. Lecture notes in computer science, vol. 4666* (pp. 89–96). Springer.

Näätänen, R. (1982). Processing negativity: An evoked-potential reflection of selective attention. *Psychological Bulletin, 92*(3), 605–640. https://doi.org/10.1037/0033-2909.92.3.605

Näätänen, R. (1988). Implications of ERP data for psychological theories of attention. *Biological Psychology,* 26(1–3), 117–163. https://doi.org/10.1016/0301-0511(88)90017-8

Näätänen, R. (1990). The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. *Behavioral and Brain Sciences, 13*(2), 201–233. https://doi.org/10.1017/S0140525X00078407

Näätänen, R. (1992). *Attention and Brain Function.* Lawrence Erlbaum Associates, Inc

Näätänen, R., Kujala, T., & Winkler, I. (2011). Auditory processing that leads to conscious perception: a unique window to central auditory processing opened by the mismatch negativity and related responses. *Psychophysiology, 48*(1), 4–22. https://doi.org/10.1111/j.1469-8986.2010.01114.x

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24*(4), 375–425. https://doi.org/10.1111/j.1469-8986.1987.tb00311.x

Näätänen, R., Simpson, M., & Loveless, N. E. (1982). Stimulus deviance and evoked potentials. *Biological Psychology, 14*(1–2), 53–98. https://doi.org/10.1016/0301-0511(82)90017-5

Nelson, D. A., Lassman, F. M. (1968). Effects of inter signal interval on the human auditory evoked response. *Journal of the Acoustical Society of America, 44*(6), 1529–1532. https://doi.org/10.1121/1.1911292

Nelson, D. A., & Lassman, F. M. (1973). Combined effects of recovery period and stimulus intensity on the human auditory evoked vertex response. *Journal of Speech and Hearing Research, 16*(2), 297–308. https://doi.org/10.1044/jshr.1602.297

Nelson, D. A., & Lassman, F. M. (1977). Re-examination of the effects of periodic and aperiodic stimulation on the auditory-evoked vertex response. *International Journal of Audiology, 16*(5), 409–418. https://doi.org/10.3109/00206097709071854

Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: effects of response conflict and trial type frequency. *Cognitive, Affective & Behavioral Neuroscience, 3*(1), 17–26. https://doi.org/10.3758/CABN.3.1.17

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*(2), 220–246. https://doi.org/10.1037/0033-2909.126.2.220

Nogueira, A. M. L., Bueno, O. F. A., Manzano, G. M., Kohn, A. F., Pompéia, S. (2015). Late positive slow waves as markers of chunking during encoding. *Frontiers in Psychology, 6*, Article 1032. https://doi.org/10.3389/fpsyg.2015.01032

O'Connell, R. G., Balsters, J. H., Kilcullem, S. M., Campbell, W., Bokde, A. W., Lai, R., Upton, N., & Robertson, I. H. (2012). A simultaneous ERP/fMRI investigation of the P300 aging effect. *Neurobiology of Aging, 33*(10), 2448–2461. *https://doi.org/10.1016/j.neurobiolaging.2011.12.021*

Ouyang, G., Herzmann, G., Zhou, C., & Sommer, W. (2011). Residue Iteration Decomposition

(RIDE): A new method to separate ERP components on the basis of latency variability in single trials. *Psychophysiology*, *48*(12), 1631–1647. https://doi.org/10.1111/j.1469-8986.2011.01269.x

Ouyang, G., Sommer, W., & Zhou, C. (2015). Updating and validating a new framework for restoring and analyzing latency-variable ERP components from single trials with Residue Iteration Decomposition (RIDE). *Psychophysiology*, *52*, 839–856. https://doi.org/10.1111/psyp.12411

Ridderinkhof, K. R., Van Den Wildenberg, W. P. M., Segalowitz, S. J., & Carter, C. S. (2004). Neurocognitive mechanisms of cognitive control: The role of prefrontal cortex in action selection, response inhibition, performance monitoring, and reward-based learning. *Brain and Cognition*, *56*(2), 129–140. https://doi.org/10.1016/j.bandc.2004.09.016

Pascual-Marqui, R. D. (1999). Review of methods for solving the EEG inverse problem. *International Journal of Bioelectromagnetism*, *1*(1), 75–86.

Pascual-Marqui, R. D. (2002). Standardised low resolution brain electromagnetic tomography (sLORETA): technical details. *Methods & Findings in Experimental & Clinical Pharmacology*, *24* (Suppl. D), 5–12.

Pascual-Marqui, R. D. (2007). Discrete, 3D distributed, linear imaging methods of electric neuronal activity. Part 1: Exact, zero error localization. *arXiv*. https://arxiv.org/abs/0710.3341

Pascual-Marqui, R. D. (2009). Theory of the EEG inverse problem. In S. Tong & N. Thakor (Eds.). *Quantitative EEG analysis: methods and clinical applications* (pp. 121–140). Boston: Artech House

Pascual-Marqui, R. D., Esslen, M., Kochi, K., & Lehmann, D. (2002). Functional imaging with low-resolution brain electromagnetic tomography (LORETA): a review. *Methods & Findings in Experimental & Clinical Pharmacology*, *24*(Suppl C), 91–95.

Pascual-Marqui, R. D., Lehmann, D., Koukkou, M., Kochi, K., Anderer, P., Saletu, B., Tanaka, H., Hirata, K., John, E. R., Prichep, L., Biscay-Lirio, R., & Kinoshita, T. (2011). Assessing interactions in the brain with exact low-resolution electromagnetic tomography. *Philosophical Transactions of the Royal Society A*, *369*(1952), 3768–3784. https://doi.org/10.1098/rsta.2011.0081

Pereira, D. R., Cardoso, S., Ferreira-Santos, F., Fernandes, C., Cunha-Reis, C., Paiva, T. O., Almeida, P. R., Silveira, C., Barbosa, F., & Marques-Teixeira, J. (2014). Effects of inter-stimulus interval (ISI) duration on the N1 and P2 components of the auditory event-related potential. *International Journal of Psychophysiology*, *94*(3), 311–318. https://doi.org/10.1016/j.ijpsycho.2014.09.012

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Reviews Neuroscience*, *35*, 75–89. https://doi.org/10.1146/annurev-neuro-

062111-150525

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology, 118*(10), 2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Polich, J., Eischen, S. E., & Collins, G. E. (1994). P300 from a single auditory stimulus. *Electroencephalography and Clinical Neurophysiology/ Evoked Potentials*, *92*(3), 253–261. https://doi.org/10.1016/0168-5597(94)90068-X

Polich, J., & Margala, C. (1997). P300 and probability: Comparison of oddball and single-stimulus paradigms. *International Journal of Psychophysiology, 25*(2), 169–176. https://doi.org/10.1016/S0167-8760(96)00742-8

Pritchard, W. S., Shappell, S. A., & Brandt, M. E. (1991). Psychophysiology of N200/N400: A review and classification scheme. In J. R. Jennings & P. K. Ackles (Eds.), *Advances in psychophysiology: A research annual* (Vol. 4, pp. 43–106). London: Jessica Kingsley.

Ramautar, J. R., Kok, A., & Ridderinkhof, K. R. (2004). Effects of stop-signal probability in the stop-signal paradigm: The N2/P3 complex further validated. *Brain and Cognition*, *56*, 234–252. https://doi.org/10.1016/j.bandc.2004.07.002

Ritter, W., Simson, R., Vaughan, H. G., & Friedman, D. (1979). A brain event related to the making of a sensory discrimination. *Science, 203*(4387), 1358–1361. https://doi.org/10.1126/science.424760

Rohrbaugh, J. W., Syndulko, K., & Lindsley, D. B. (1978). Cortical slow negative waves following non-paired stimuli: Effects of task factors. *Electroencephalography and Clinical Neurophysiology*, *45*(5), 551–567. https://doi.org/10.1016/0013-4694(78)90156-6

Rubia, K., Russell, T., Overmeyer, S., Brammer, M. J., Bullmore, E. T., Sharma, T., Simmons, A., Williams, S. C., Giampietro, V., Andrew, C. M., & Taylor, E. (2001). Mapping motor inhibition: conjunctive brain activations across different versions of go/no-go and stop tasks. *NeuroImage*, *13*, 250-261. http://doi.org/10.1006/nimg.2000.0685

Ruchkin, D. S., Canoune, H. L., Johnson, R., & Ritter, W. (1995). Working memory and preparation elicit different patterns of slow wave event-related brain potentials. *Psychophysiology, 32*(4), 399–410. https://doi.org/10.1111/j.1469-8986.1995.tb01223.x

Ruchkin, D. S., Johnson, R., Canoune, H., & Ritter, W. (1990). Short-term memory storage and retention: an event-related brain potential study. *Electroencephalography and Clinical Neurophysiology, 76*(5), 419–439. https://doi.org/10.1016/0013-4694(90)90096-3

Ruchkin, D. S., Johnson, R., Mahaffey, D., & Sutton, S. (1988). Toward a functional categorization of slow waves. *Psychophysiology, 25*(3), 339–353. https://doi.org/10.1111/j.1469-8986.1988.tb01253.x

Ruchkin, D. S., Sutton, S., Mahaffey, D., & Glaser, J. (1986). Terminal CNV in the absence of motor response. *Electroencephalography and Clinical Neurophysiology*, *63*(5), 445–

463. https://doi.org/10.1016/0013-4694(86)90127-6

Rushworth, M. F. S., Walton, M. E., Kennerley, S. W., & Bannerman, D. M. (2004). Action sets and decisions in the medial frontal cortex. *Trends in Cognitive Sciences*, *8*(9), 410-417. https://doi.org/10.1016/j.tics.2004.07.009

Sass, D. A., & Schmitt, T. A. (2010). A comparative investigation of rotation criteria within exploratory factor analysis. *Multivariate Behavioral Research*, *45*(1), 73–103. https://doi.org/10.1080/00273170903504810

Scharf, F., & Nestler, S. (2018a). Exploratory structural equation modelling for event-related potential data—An all-in-one approach? *Psychophysiology*, *56*(3), 1–19. https://doi.org/10.1111/psyp.13303

Scharf, F., & Nestler, S. (2018b). Principles behind variance misallocation in temporal exploratory factor analysis for ERP data: Insights from an inter-factor covariance decomposition. *International Journal of Psychophysiology*, *128*, 119–136. https://doi.org/10.1016/j.ijpsycho.2018.03.019

Schmitt, T. A., & Sass, D. A. (2011). Rotation criteria and hypothesis testing for exploratory factor analysis: Implications for factor pattern loadings and interfactor correlations. *Educational and Psychological Measurement*, *71*(1), 95–113. https://doi.org/10.1177/0013164410387348

Schröger, E., Marzecová, A., & SanMiguel, I. (2015). Attention and prediction in human audition: a lesson from cognitive psychophysiology. *European Journal of Neuroscience*, *41*(5), 641–664. https://doi.org/doi:10.1111/ejn.12816

Shibasaki, H., Barrett, G., Halliday, E., & Halliday, A. M. (1980). Components of the movement-related cortical potential and their scalp topography. *Electroencephalography and Clinical Neurophysiology*, *49*, 213–226. https://doi.org/10.1016/0013-4694(80)90216-3

Simson, R., Vaughan, H. G., Jr, & Ritter, W. (1977). The scalp topography of potentials in auditory and visual Go/NoGo tasks. *Electroencephalography and Clinical Neurophysiology*, *43*(6), 864–875. https://doi.org/10.1016/0013-4694(77)90009-8

Spencer, K. M., Dien, J., & Donchin, E. (2001). Spatiotemporal analysis of the late ERP responses to deviant stimuli. *Psychophysiology*, *38*(2), 343–358. https://doi.org/10.1111/1469-8986.3820343

Spencer, K. M., & Polich, J. (1999). Poststimulus EEG spectral analysis and P300: attention, task and probability. *Psychophysiology.*, *36*(2), 220–232. https://doi.org/10.1111/1469-8986.3620220

Starr, A., Aguinaldo, T., Roe, M., & Michalewski, H. J. (1997). Sequential changes of auditory processing during target detection: Motor responding versus mental counting. *Electroencephalography and Clinical Neurophysiology*, 105, 201–212.

https://doi.org/10.1016/S0924-980X(97)00016-7

Steiner, G. Z., Barry, R. J., & Gonsalvez, C. J. (2014a). Nontarget-to-nontarget interval determines the nontarget P300 in an auditory equiprobable Go/NoGo task. *International Journal of Psychophysiology*, *92*(3), 113–121. https://doi.org/10.1016/j.ijpsycho.2014.03.010

Steiner, G. Z., Barry, R. J., & Gonsalvez, C. J. (2014b). Stimulus-to-matching-stimulus interval influences N1, P2, and P3b in an equiprobable Go/NoGo task. *International Journal of Psychophysiology*, *94*(1), 59–68. https://doi.org/10.1016/j.ijpsycho.2014.07.003

Steiner, G. Z., Barry, R. J., & Gonsalvez, C. J. (2016). Sequential processing and the matching-stimulus interval effect in ERP components: An exploration of the mechanism using multiple regression. *Frontiers in Human Neuroscience*, *10*, 1–14. https://doi.org/10.3389/fnhum.2016.00339

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica*, *30*, 276–315. https://doi.org/10.1016/0001-6918(69)90055-9

Squires, K. C., Donchin, E., Herning, R. I., & McCarthy, G. (1977). On the influence of task relevance and stimulus probability on event-related-potential components. *Electroencephalography and Clinical Neurophysiology*, *42*(1), 1–14. https://doi.org/10.1016/0013-4694(77)90146-8

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology*, *38*(4), 387–401. https://doi.org/10.1016/0013-4694(75)90263-1

Talati, A., & Hirsch, J. (2005). Functional specialization within the medial frontal gyrus for perceptual go/no-go decisions based on "what," "when," and "where" related information: An fMRI study. *Journal of Cognitive Neuroscience*, *17*(7), 981–993. https://doi.org/10.1162/0898929054475226

Taylor, M. J., Batty, M., Chaix, Y., & Démonet, J. F. (2003). Neurophysiological measures and developmental dyslexia: auditory segregation analysis. *Current Psychology Letters. Behaviour, Brain & Cognition*, *10*(1), Article 2003. https://doi.org/10.4000/cpl.101

Thurstone, L. L. (1947). *Multiple factor analysis*. Chicago: University of Chicago Press.

Tong, Y., Melara, R. D., & Rao, A. (2009). P2 enhancement from auditory discrimination training is associated with improved reaction times. *Brain research*, *1297*, 80–88. https://doi.org/10.1016/j.brainres.2009.07.089

Tsukiura, T., Fujii, T., Takahashi, T., Xiao, R., Inase, M., Iijima, T., Yamadori, A., & Okuda, J. (2001). Neuroanatomical discrimination between manipulating and maintaining processes involved in verbal working memory; a functional MRI study. *Cognitive Brain Research*, *11*(1), 13–21. https://doi.org/10.1016/s0926-6410(00)00058-8

Van Boxtel, G. J. M. (1998). Computational and statistical methods for analyzing event-related potential data. *Behavior Research Methods, Instruments, & Computers*, *30*(1), 87–102. https://doi.org/10.3758/BF03209419

Vaughan, H. G., Costa, L. D., & Ritter, W. (1968). Topography of the human motor potential. *Electroencephalography and Clinical Neurophysiology*, *25*, 1–10.

Verleger, R. (1987). Sequential effects on P3 in a counting task: A partial replication. *Biological Psychology*, *25*(3), 221–246. https://doi.org/10.1016/0301-0511(87)90049-4

Verleger, R., Hamann, L. M., Asanowicz, D., & Śmigasiewicz, K. (2015). Testing the S-R link hypothesis of P3b: The oddball effect on S1-evoked P3 gets reduced by increased task relevance of S2. *Biological Psychology*, *108*, 25–35. https://doi.org/10.1016/j.biopsycho.2015.02.010

Verleger, R., Grauhan, N., & Śmigasiewicz, K. (2016). Go and no-go P3 with rare and frequent stimuli in oddball tasks: A study comparing key-pressing with counting. *International Journal of Psychophysiology*, *110*, 128–136. https://doi.org/10.1016/j.ijpsycho.2016.11.009

Verleger, R., Metzner, M., Ouyang, G., Śmigasiewicz, K., & Zhou, C. (2014). Testing the stimulus-to-response bridging function of the oddball-P3 by delayed response signals and residue iteration decomposition (RIDE). *NeuroImage*, *100*, 271–280. https://doi.org/10.1016/j.neuroimage.2014.06.036

Wessel, J. R. (2018). Prepotent motor activity and inhibitory control demands in different variants of the go/no-go paradigm. *Psychophysiology*, *55*(3), Article e12871. https://doi.org/10.1111/psyp.12871

Wijers, A. A., Lange, J. J., Mulder, G., & Mulder, L. J. M. (1997). An ERP study of visual spatial attention and letter target detection for isoluminant and nonisoluminant stimuli. *Psychophysiology*, *34*(5), 553–565. https://doi.org/10.1111/j.1469-8986.1997.tb01742.x

Woods, D. L. (1995). The component structure of the N1 wave of the human auditory evoked potential. *Electroencephalography and Clinical Neuropsychology*, *44*, 102–109.

Yeung, N., Botvinick, M. M., & Cohen, J. D. (2004). The neural basis of error detection: Conflict monitoring and the error-related negativity. *Psychological Review*, *111*, 931–959. https://doi.org/10.1037/0033-295X.111.4.931

Zhang, F., Deshpande, A., Benson, C., Smith, M., Eliassen, J., & Fu, Q-J. (2011). The adaptive pattern of the auditory N1 peak revealed by standardized low-resolution brain electromagnetic tomography. *Brain Research*, *1400*, 42–52. https://doi.org/10.1016/j.brainres.2011.05.036.

Appendices

Appendix A. Statement of Contribution of Others

Chapter 2 (Fogarty et al., 2019)

JSF and RJB conceptualised this study. JSF performed the data collection, analyses, and interpretation of the outcomes under the supervision of RJB and GZS. The journal article was drafted and finalised by JSF following critical revisions provided by RJB and GZS. All authors approved the final article prior to submission.

Chapter 3 (Fogarty et al., 2020b)

JSF conceptualised this study. JSF performed the data collection, analyses, and interpretation of the outcomes under the supervision of RJB and GZS. The journal article was drafted and finalised by JSF following critical revisions provided by RJB and GZS. All authors approved the final article prior to submission.

Chapter 4 (Fogarty et al., 2020a)

JSF and RJB conceptualised this study. JSF performed the data collection, analyses, and interpretation of the outcomes under the supervision of RJB and GZS. The journal article was drafted and finalised by JSF following critical revisions provided by RJB and GZS. All authors approved the final article prior to submission.

Chapter 5 (Fogarty et al., submitted)

JSF conceptualised this study. JSF performed the data collection, analyses, and interpretation of the outcomes under the supervision of RJB and GZS. The journal article was drafted and finalised by JSF following critical revisions provided by RJB and GZS. All authors approved the final article prior to submission.

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Appendix B. Chapter 1 Literature Analyses

The literature analyses summarised in Chapter 1, Figure 2 (p. 9), were conducted using the results of three separate PubMed literature searches to help characterise the current state of the Go/NoGo (and oddball) ERP literature.

1.1. Probability literature searches and the derived studies

PubMed searches of the Go/NoGo and oddball probability literature were conducted to identify the number of simple (i.e., two-stimulus) uncued Go/NoGo studies involving statistical analyses of global stimulus probability effects on ERP components. General search terms were used without restrictions (e.g., of time range) to maximise the initial search results: (1) "*Go NoGo Probability*" (search date: 26/03/19), and (2) "*Oddball Probability*" (search date: 27/05/19). Irrelevant (or unusable) articles were rejected if they were not (i) journal articles, (ii) in english, (iii) studies of humans, or (iv) they did not involve an experiment utilising a Go/NoGo (or oddball) task. Details of the remaining articles were then recorded, including the number of imperative stimuli in the Go/NoGo task, the stimulus modality (or modalities), whether warning stimuli (cues) or masks were used, the global target stimulus probability level(s), and the primary measures used (i.e., EEG, Behavior, fMRI etc). Any articles with tasks using warning stimuli or masks, or involving more than two imperative stimuli (i.e., multiple targets, nontargets, or deviants) were then excluded from the final summary of the "Go NoGo Probability" and "Oddball Probability" search outcomes shown in Chapter 1, Figure 2 (p. 9). The 226 studies remaining across both literature searches were then examined to derive the number of simple and uncued Go/NoGo studies, including an equiprobable condition, involving statistical analyses of stimulus probability effects on ERP components.

1.2. Go/NoGo AND Oddball analysis: crossover between literatures

To illustrate the crossover (or distinction) between the Go/NoGo and oddball literatures, an additional PubMed search was conducted using the terms "*(Go NoGo) AND Oddball*" (search date: 03/03/20) to get an approximate number of articles including (or mentioning) both Go/NoGo and oddball tasks. The number of duplicate (or common) studies identified between the two probablity literature analyses were also counted as an additional measure of the relationship between the Go/NoGo and oddball research areas. Seventeen journal articles were identified in the PubMed results in total, and one duplicate was identified between the two probability literature search outcomes described above, suggesting that there is little crossover between the Go/NoGo and oddball literatures.

1.3. Further comments

"Go NoGo" was used in the PubMed searches because other common variations of the term (i.e., "Go/NoGo", "go-nogo", etc) resulted in more limited search results. A formal publication of the literature analyses described here is being prepared separate to this thesis; however, the search outcomes are available upon request.

Appendix C. Published Journal Articles

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Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2019). Sequential processing in the classic oddball task: ERP components, probability, and behavior. *Psychophysiology*, *56*(3), Article e13300. https://doi.org/10.1111/psyp.13300

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2020). Auditory stimulus- and response-locked ERP components and behaviour. *Psychophysiology*, *57*(5), Article e13538. https://doi.org/10.1111/psyp.13538

Fogarty, J. S., Barry, R. J., & Steiner, G. Z. (2020). The first 250 ms of auditory processing: No evidence of early processing negativity in the Go/NoGo task. *Scientific Reports*, *10*(1), Article 4041. https://doi.org/10.1038/s41598-020-61060-9